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CONTENTS.

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Astronomy and Astro-Physics.

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General Astronomy.

MARS.*

WILLIAM H. PICKERING.

Now that the opposition of 1892 has passed into history, it may be well to give a brief summary of the observations made at Arequipa this year, preparatory to a more complete publication elsewhere. With one exception, the planet has been observed every night continuously, from July 9 until September 24, when the lens of the telescope was reversed, for photographic work, and the regular observations came to an end. Since the beginning of the year Mr. Douglass and myself have made 373 drawings of different features of the planet, thirteen of them being colored. Numerous micrometric measurements of the equatorial, polar, and phase diameters have been made. A large number of measurements of the snow, and other observations for correcting the physical ephemeris of the planet have been collected. Ninety-two stations have been located upon the planet micrometrically, many of them having been observed upon several different dates. Besides these, measurements of the clouds, and the breadths of the lakes, canals, and minor features have been obtained. Considerable data has thus been collected at this opposition for future discussion.

Turning now to what we may call the definite conclusions to be derived from our observations, we may say:—

(1st). That the polar caps are clearly distinct in appearance from the cloud formations, and are not to be confounded with them.

(2d). That clouds undoubtedly exist upon the planet, differing however, in some respects from those upon the Earth, chiefly as regards their density and whiteness.

(3d). There are two permanently dark regions upon the planet, which under favorable circumstances appear blue, and are presumably due to water.

* Communicated by the author.

(4th). Certain other portions of the surface of the planet are undoubtedly subject to gradual changes of color, not to be explained by clouds.

(5th). Excepting the two very dark regions referred to above, all of the shaded regions upon the planet have at times a greenish tint. At other times they appear absolutely colorless. Clearly marked green regions are sometimes seen near the poles.

(6th). Numerous so-called canals exist upon the planet, substantially as drawn by Professor Schiaparelli. Some of them are only a few miles in breadth. No striking instances of duplication have been seen at this opposition.

(7th). Through the shaded regions run certain curved branching dark lines. They are too wide for rivers, but may indicate their courses.

(8th). Scattered over the surface of the planet, chiefly on the side opposite to the two seas, we have found a large number of minute black points. They occur almost without exception at the junctions of the canals with one another, and with the shaded portions of the planet. They range from thirty to one hundred miles in diameter, and in some cases are smaller than the canals in which they are situated. Over forty of them have been discovered, and for convenience we have termed them lakes.

No repetition of the phenomena connected with the melting snow, which occurred in July has been observed. The Y mark has assumed its customary appearance, so that the narrowing of the southern branch seems to have been a temporary phenomenon, and was probably due to clouds. The central branch is now continuously visible, but its southern extremity which connected it with the snow has disappeared. The southern branch of the Y also seems to be gradually fading out.

Clouds have on several occasions been observed to project beyond the terminator, and also beyond the limb, thus confirming the observations made at the Lick Observatory. The height of these clouds has been measured, and it appears that some of them attained an altitude of at least twenty miles,—a height considerably greater than that attained by terrestrial clouds. This is a result naturally to be expected from the small mass of the planet. No direct measures have been possible of the density of the atmosphere at the planet's surface, but indirect observations lead us to conclude that it is less than that at the surface of the Earth, but probably not as much as ten times less.

A curious feature of the observations has been the distinct flattening at the planet's poles, amounting to at least $\frac{1}{70}$. From

theoretical considerations, unless we assume a rather improbable internal structure, it cannot exceed $\frac{1}{200}$, and that is approximately the figure which Professor Young derived from his measurements. Herschel made $\frac{1}{16}$, Arago $\frac{1}{30}$, and other observers have obtained various results, in general greater than ours. The above figure must not be considered by any means final, but merely as an approximate minimum, since our computations have not as yet been completed. That the flattening at opposition was considerable was very evident. As no such conspicuous discrepancies among different observers occur in the case of the other planets, I am inclined to think that the variations may be real, and due perhaps to an equatorial cloud formation. Clouds are certainly very frequent upon the sunrise terminator, particularly towards the equator. In any case this is an interesting matter for investigation at future oppositions.

As the snow in melting receded towards the pole, there was a narrow, nearly straight region upon which it lingered longer than elsewhere. At present the snow is divided into two sections one long and narrow, the other of irregular shape, and somewhat mottled. The appearance is such as might be produced by a mountain range and an area of irregular elevation, with a valley lying between them. It was from this supposed valley that the dark line issued in July connecting it with the Northern Sea.

Upon August 5, in the region just to the north of Solis Lacus, latitude — 20°, a small but conspicuous white spot appeared. It was conspicuous from being brighter than any other spot upon the planet save the southern snow cap, which it exactly resembled in color.

A similar but much smaller spot was also noticed further to the southwest. Both spots had disappeared by August 7, but careful measurements upon two nights, and several drawings, had already accurately located their positions. The larger of these spots measured about 60 miles in length by perhaps 40 in width, and was much brighter than any cloud that I have ever seen upon the planet. I am inclined to attribute both of these spots to snow. We have frequently seen small white points lying along the line which bounds the shaded regions upon the north. Early in August the whole northern sphere of the Equatorial Sea was bounded by a narrow white line, while later a similar line bounded the Northern Sea upon the west. These lines were apparently due to cloud, and were not as bright as the spots of snow referred to above. Although nearly a thousand miles long, they could hardly have exceeded thirty miles in breadth.

Although Mars has been nearer the Earth at this past opposition than it will be again for fifteen years, I am quite inclined to believe that it will be better seen in 1894 than it has been this year. My reasons for this statement are as follows:—In the first place, its distance from the Earth will not be very much greater than it has been this year, and indeed for part of the time it will be less remote than it was when many of our most interesting observations were secured. Secondly, it will be much farther north, where the great northern telescopes can be used upon it to much greater advantage. Thirdly, following the melting of the southern snow, the Arean atmosphere was filled with clouds, and these did not clear away satisfactorily until the very end of August, or long after the opposition was over. It was only after the clouds began to clear, that the Arean lakes, which have proved such an interesting feature of this opposition, began to show to their full advantage. Owing to the change of seasons upon Mars, little of this latter difficulty should be experienced at the next opposition, and it is thought that many lakes and other delicate features still remain undiscovered, which may reveal themselves at that time. Could the great 40-inch telescope of Southern California then be completed, undoubtedly the best views of the planet would be obtained at that point, but if it is not, the Lick telescope can certainly be used to greater advantage, and the Arequipa telescope to no less advantage, than was the case this year.

AREQUIPA, PERU, September 28, 1892.

SILVERING GLASS MIRRORS.

A. A. COMMON.

The importance of a good reflecting surface in such instruments as the modern silver-on-glass reflecting telescope and the equatorial coudé is obvious. As a rule the silver surface if fairly protected from dust and damp will last many years with but slight loss of light, but must be renewed frequently if the best results are to be obtained. Many different processes and methods of silvering have been from time to time published by different people, and it becomes of some interest to examine these with a view of finding out the particular one that suits certain cases.

Having used reflecting telescopes for many years I have had occasion to try a great number of experiments with a view of get-

ting a good process. It would be tedious to give these in detail, but it may be useful to give some few instances where satisfactory results have been obtained.

The process of depositing the metallic silver on a glass surface is an empirical one; the conditions affecting the reactions are so various that hard-and-fast rules cannot be laid down. The temperature in which the process is carried on seems perhaps the most important thing to be considered, ranging as it may from 35° or 40° to 104° F. according to the reducing agent employed.

I have had occasion to look up the processes published from time to time; some of these are of sufficient interest to be given briefly.

Baron Liebig found in 1835 that on heating aldehyde with an ammoniacal solution of nitrate of silver in a glass vessel a brilliant deposit of metallic silver was deposited on the surface of the glass. To this observation is due the modern process of silvering glass.

The next important step seems to have been taken by Cimeg, who, in 1861, patented a process for silvering mirrors (where of course only the surface against the glass is used) by what has since been known as the Rochelle-salt process. This patent is No. 619, 1861. After cleaning the glass in the usual way he washes the surface with Rochelle-salt solution 1 in 200. For 1 sq. yard of glass he takes 20 grammes of nitrate of silver in solution and adding it to ammonia of commerce till a brown precipitate commences to be produced; to this is added a solution of 14 grammes of Rochelle salts. Using the mixture in this proportion when it becomes turbid he pours it over the glass plate, which has an inclination of 1 in 40, for 30 minutes at a temperature of 68°.

In 1862 Cimeg has another process patented (No. 2314). He uses 20 grammes of Rochelle salts in 300 grammes of water, 20 grammes of nitrate of silver in 15 grammes of water with ammonia to clear; but in place of using a weak solution of Rochelle salts on the surface of the glass before silvering he rubs on the juice of apples, currants, sorbs, or other berries before silvering.

In 1873 Woerther uses glucose as the reducing agent.

In 1876 Pratt patents a process (No. 1259) in which before silvering he treats the glass with 1 part of protochloride of tin in 100 parts water. For large plates he uses 1 part protochloride of tin, 3 drachms of oxalate of ammonia, ½ lb. putty powder, 4 pints distilled water; this is rubbed on and allowed to dry; he then uses a solution of 2 parts oxalate of ammonia, 4 parts

grape-sugar, 1 part lime, 1 part potassic cyanide, in 1000 parts water. In silvering he uses tartaric acid, but does not give details.

There are a few more patents for silvering since the last date of no importance.

In 1881 Piazzi Smyth gives, in 'British Journal of Photography Almanac,' Martin's process in full. This is a pretty well-known process, and in some hands has worked very well. Many other processes, in which the chief variation is the reducing agent employed, have from time to time appeared in the various scientific journals—the most important being that published by Mr. J. A. Brashear in the 'English Mechanic,' vol. 31, p. 327. This is a most excellent process and for ordinary work, when the glass can be put in face downwards, the best I know. This I give further on as I use it.

In the 'Encyclopædia Britannica,' vol. 16, p. 500, two processes, hot and cold are given; these, though mainly relating to the silvering of ordinary looking-glasses, have a bearing on the process as used for silvering mirrors.

"In the former method there is employed a horizontal double-bottomed metallic table which is heated with steam from 35° to 40° C. The glass to be silvered is cleaned thoroughly with wet whiting, then washed with distilled water and prepared for the silver with a sensitizing solution of tin, which is well rinsed off before it is removed to the silvering table. The table being raised to the proper temperature the glass is laid and the silvering solution at once poured over it, before the heat of the table has time to dry any part of the surface of the glass. The solution used is prepared as follows:—In half a litre of distilled water 100 grammes of nitrate of silver are dissolved; to this is added of liquid ammonia (sp. gr. 0.880) 62 grammes; the mixture is filtered and made up to 8 litres with distilled water, and 7.5 grammes of tartaric acid dissolved in 30 grammes of water are mixed with the solution: about 2.5 litres are poured over the glass for each superficial metre to be silvered. The metal immediately begins to deposit on the glass, which is maintained at about 40° C. (104° F.), and in little more than half an hour a continuous coating of silver is formed. The surface of silver is then cleaned by very carefully wiping with a very soft chamois leather and treated a second time with a solution like the first, but containing a double quantity of tartaric acid. The solution is applied in two portions, and thereafter the glass is once more carefully cleaned of all unattached silver and refuse and removed to a side room for backing up."

"In silvering by the cold process advantage is taken of the power of inverted sugar to reduce the nitrate of silver. This process has been adopted for the silvering of mirrors of astronomical telescopes, notably of Leverrier's great telescope in the Paris Observatory. For ordinary mirror silvering the following is the process recommended by H. E. Benrath :—Two solutions are prepared the first of which contains the silver salt, the second the sugar preparation. For the silver solution 800 gammes of nitrate of silver and 1,200 grammes of nitrate of ammonium are dissolved in 10 litres of water and 1.3 kilos of pure caustic soda in 10 litres of water, and of each of these solutions 1 litre is added to 8 litres of water, which is allowed to rest till the sediment forms and then decanted. The second solution—inverted sugar—is prepared by dissolving 150 grammes of loaf-sugar with 15 grammes of vinegar in 0.5 litre of water, and boiling the solution for half an hour. After cooling it is made up with water to 4,200 cubic centimetres. The silvering is done on horizontal tables in a well-lighted and moderately heated apartment, and the glass is cleaned with scrupulous care. For each square centimetre of glass operated on 15 cubic centimetres of the silver solution above described are measured out, and from 7 to 10 per cent of the solution of inverted sugar is added, both being quickly stirred together and poured rapidly and evenly over the glass. The reduction immediately begins and the solution exhibits tints passing through rose, violet, and black, till in about seven minutes it again becomes transparent and the deposit of metal is complete. This first deposit is extremely thin and allows the transmission of bluish rays. The exhausted solution with floating and unattached dust-like particles of silver is carefully wiped off, the silvered surface washed with distilled water, and again treated with the mixed solutions to the extent of half the quantity used in the first application. The finished surface is wiped and washed in the most thorough manner—for the least trace of caustic soda left would destroy the mirror. The further processes are the same in both methods of silvering."

In Brashear's process, already mentioned, the most important thing is the sugar solution forming the reducing agent. This greatly improves by keeping—a solution that has been made some months being much more effective than a newly made one. I find it convenient to have always some Winchester quarts of it in stock ready for use. I have for convenience varied his proportions slightly and thus give them as I have found them work so well. For the sugar solution I add to a 10% solution of loaf-

sugar, in distilled water, 10% of alcohol and ½% of nitric acid. Solutions of 10% of nitrate of silver and of caustic potash are separately prepared, the latter one as wanted. These, with sufficient ammonia and a very dilute solution of nitrate of silver, and also a similar very dilute one of ammonia, are prepared, the latter in order to obtain that pale brown color of the ammoniated solution of nitrate of silver that it is absolutely necessary to have before adding the reducing agent.

Having selected a suitable dish to contain the liquid, in which the mirror can be placed face downwards with about ½ or ¾ inch of liquid underneath, find on the basis of 1 of silver-nitrate solution to 4 of the total required liquid the amount of silver solution needed; to this add ammonia till the first formed precipitate is dissolved, then add one-half of this quantity of the potash solution (this is a variation from Mr. Brashear's formula that I have found works well), and again add ammonia till the mixed solution is quite clear, taking care to put in only sufficient ammonia for that purpose; then add the weak solution of nitrate of silver till a clear brown color is obtained; should this become a dark brown some of the weak solution of ammonia will bring it to a pale brown color, which must persist if the solution is left standing some time.

The mirror, previously cleaned with nitric acid and distilled water, and suspended in the dish in distilled water of sufficient amount to make up on the addition of the solutions the total liquid required, is lifted out and the prepared solutions mixed with the distilled water and an amount of the reducing solution equal to about one-half that of the nitrate of silver solution more or less as the temperature is under or over 60°; as soon as all is intimately mixed the mirror is immersed with one movement, beginning by dipping the edge first and lowering so as to prevent any air bubbles forming under the glass. In from three to five minutes the silver begins to form on the mirror, the solution changing from pink to dark brown and black, the film thickens quickly and in from twenty-five to thirty minutes sufficient silver is deposited. The mirror can then be washed and put to soak in distilled water for a few hours, then taken out and dried and polished in the usual way, that is with a soft pad of clean chamois, and going all over the mirror with light strokes till the bloom is all removed and a fair polish is obtained, finishing with a very little of the finest washed rouge, quite dry, lightly dusted on the pad; it is very important to well consolidate the film of silver by the unrouged pad before using any polishing powder.

It is a very good plan for any one who is not in the habit of silvering, or to whom the process is strange, to try the proportions of the solutions on some small pieces of glass till a satisfactory proportion for the temperature (for that is the chief factor in varying the amount of reducing solution necessary) of the room in which he is working. The most important thing (after the solutions) is the proper cleansing of the glass, for on the proper preparation of the surface of the glass a very great deal depends.

As already stated, this process is used when the glass to be silvered can be suspended in the liquid; it is not suitable when we attempt to silver surfaces face upwards. The mud formed settles down and prevents any proper deposition of silver; this was a source of considerable trouble when it was required to silver the three-foot mirror, and a pneumatic arrangement was eventually made to hold the mirror by the back, so that it could be silvered face downwards, and up to that size the silvering could be managed.

The great size of the five-foot mirror and its enormous weight (over half a ton without the cell) made it dangerous to suspend it, and the question of silvering became a serious one. In making experiments in order to get rid of the mud formed in the process last mentioned, it was found that by leaving out the potash the silver was deposited from a nearly clear liquid and no mud was formed and the first five-foot mirror was very successfully silvered in this manner. The solutions of silver and sugar are used in the same proportions without potash, but it is found advisible to use a stronger total mixture. For subsequent silvering of the five-foot mirror the Rochelle-salt process has been used, and this for the deposition of the silver on a surface face up seems to be the best, using, if necessary, two or more applications.

In preparing a large mirror for silvering in this manner it is necessary to form it into a dish by using a band of paraffined brown paper round the edge, standing up an inch or more all round, and mounting the mirror on a swinging support, so that it can be tipped up to throw off the water or spent solutions; in the case of the five-foot mirror, when mounted on the machine this tipping up could be done by the same arrangement used for placing the mirror vertical for testing.

The proportions of solutions used for the five-foot were for each application; 3000 cubic centimetres of silver solution as before ammoniated as already described, and 500 c. c. of Rochelle-salt solution, with about 29,000 c. c. of distilled water; this remained on the mirror 28 minutes; another simllar application

was left on for 30 minutes; after thorough washing, distilled water was left on for some hours and the film dried and polished.

A very fine film of silver was deposited on a five-foot mirror, using one application only of 4,000 c. c. of silver solution and 750 c. c. of Rochelle-salt solution; this after one year was found to be in a very good state indeed; this was on the first mirror which, from some defect in the glass, could not be made into a good mirror. The disk of glass was returned to the makers to be replaced by another. I took this opportunity of removing and collecting the whole of the silver by dissolving it in nitric acid. The assay of the deposit gave a total weight of 26.5 grains of silver on a surface of 2,800 square inches, equal to a thickness of $\frac{1}{280000}$ inch, almost exactly; in actual weight somewhat between that of a threepenny and a fourpenny piece, not a large amount of the 400 grammes of nitrate of silver used in depositing the film. The actual waste need not be very much, as the chloride of silver can be easily deposited by the addition of common salt to the spent solutions and the silver thus recovered.

It will be seen that the various processes all have the ammoniated solution of nitrate of silver, and differ only in the reducing agent. The preparation of this solution, in order to get the pale brown color already spoken of, demands some care. If the solution is too strong, on the addition of ammonia a very flocculent deposit is formed, difficult of redissolution. If after the solution is cleared by the addition of ammonia a strong solution of silver nitrate is added to get this color, this flocculent deposit occurs; but if the weak solution advised be used, there is not any difficulty in getting the proper color free from any deposit. This is important. A word of caution may not be out of place concerning the production sometimes of a fulminate of silver, recognized by its dark grey metallic lustre. This is extremely liable to explode with great violence on the contact of almost anything; a few drops of water once sufficed to explode some in a beaker and blow it to fragments. By using moderately diluted solutions this danger is obviated. My own experience is not singular in this respect, for Mr. Brashear relates a similar occurrence.

The silver film is not always of the same quality, and experiments are needed to get more information as to what determines the greater density and coherence of some films over others. I have had surfaces of glass silvered experimentally where the film would not wash off with any amount of wet rubbing, these mostly on surfaces that had been silvered many times. Probably the glass in this case was in the best state to receive the new

deposit; certainly the condition of the surface does affect the coherence of the silver as well as the amount of the deposit, as judged by the way in which certain parts on a mirror that has been incompletely cleaned show that the deposition has begun long before other parts, necessarily resulting in an unequal thickness of film. With the most careful cleaning of a mirror I have often found that the first application did not succeed, but the second on the surface just cleaned off with nitric acid was all right. The nature of the liquid other than distilled water last in contact with the surface of the mirror seems to be the determining thing. —*Observatory*, October, 1892.

REQUEST FOR OBSERVATIONS OF NIGHT CLOUDS.*

W. FOERSTER AND O. JESSE.

Since the year 1885 a very remarkable phenomenon has been noticed in the sky in our latitude, which is of a nature to greatly excite the interest of astronomers and geophysicists. The essential substance of what has been learned so far through observations regarding the phenomenon of the so-called *luminous night-clouds* is in brief the following:

For the latitude of Berlin the phenomenon is visible only during a comparatively short portion of the year, namely from the 23d of May until the 11th of August. While in the first years it was seen quite frequently, and before midnight, during the last four years, it has appeared in nearly every instance after midnight only. The phenomenon shows itself in the form of cirrus-clouds which stand out bright against the twilight sky. This especially distinguishes them from the ordinary cirrus-clouds which with the depression of the Sun at which the luminous clouds are seen at present, appear dark on the light twilight sky. The color of the phenomenon is generally a bluish white which becomes yellowish and reddish in the close proximity of the horizon.

Frequent photographs which have been taken simultaneously at various points in the neighborhood of Berlin, show that the altitude of the luminous clouds, is constant and exceedingly great, namely equal to 82 kilometres. In consequence of this great altitude they receive light from the Sun when it is *below* the horizon, which makes them appear light on the twilight sky. They are visible only so long as the Sun shines on them; as soon

* Communicated by the authors. Scientific Journals are asked to give notices of this article.

as the shadow of the Earth passes over them, they become invisible. As a rule they commence in the morning shortly before the twilight begins, and they disappear as soon as the Sun is less than 8° to 10° below the horizon.

Of late years these clouds have been seldom seen. Within the period above stated, they have occured only about ten times, while in the first year they were quite frequent. Their appearance is subject to great changes. While they frequently consist of only a few little luminous streaks or patches, at times they appear of greater extent and with a more intense light. Especially in the last days of the period from the 2d until the 6th of August their light seems to be considerable in our latitudes. They are generally observed in the vicinity of the horizon, and over that part below which the Sun is.

Judging from the frequent observations regarding the movements of the phenomenon, which after midnight, are always from the direction NE ± 40°, it is most probable *that the movements are caused principally by a resisting medium of the inter-planetary space.* In accordance with this is the fact that in the half year after its appearance in this country the phenomenon has been observed repeatedly in the southern latitude of 53°, viz., by the meteorological observer Mr. Stubenrauch in Gunta Armas as well as several times by ship captains.

Other observations also confirm the assumption of such an annual movement, for instance at Grahamtown in 33° south latitude the phenomenon was observed on the 27th of October 1890,* and at Haverford in 40° north latitude, according to written information, it was observed on the 17th of May 1892. These times are so related that from them in connection with the time of the appearance in this country, the conclusion may be directly drawn that there is a movement of the phenomenon from north to south and back.

The luminous night clouds decrease year after year in respect to the frequency of their appearance as well as to their extent and to their intensity of light. Although, according to this, the phenomenon will have entirely disappeared within a few years, it seems, that during the next year observations will still be possible, which may give us information regarding several questions of extraordinary importance.

For this, measurements, especially of the apparent altitude of the upper limits of the luminous clouds, mainly at the time in which the upper limit of the twilight segment has the compara-

* Compare *Astron. Nach.* No. 3008.

tively small altitude of say 1° to 10°, would be of great value. The measurements will serve to decide the question whether the altitude of the clouds varies in different geographical latitudes; providing that the estimates always refer to points which lie within the upper limits of the clouds, produced by the shadow of the Earth.

Since the last year the whole of the twilight segment is comparatively seldom filled out by the luminous night clouds, and it may therefore frequently be doubtful whether the highest point of the phenomenon really lies at the limit of the Earth's shadow. In order, therefore, to make sure that the measurements will answer the said purpose, it is necessary to repeat them as often as possible at intervals of a few minutes. In the evening, besides this, this limit is generally found by the fact that within it parts of the phenomenon disappear from above, while towards morning new parts always become visible at this limit as it moves upwards. The distance of the zeniths from the upper limit of the luminous clouds in the vertical of the Sun, for the latitude of Berlin, presuming that the phenomenon now stretches over the whole of the twilight segment, may be seen from the following statement:

Depression of the Sun Below the Horizon.	Zenith Distance of the uppermost Limit.
°	°
12.0	80
12.5	83
13.0	85
13.5	86
14.0	87

Moreover, as by means of a telescope the upper limit of the phenomenon is generally seen a little higher than with the naked eye, the more so the stronger light gathering power of the telescope is, it is desirable that the telescope should always be adjusted to the limit line seen with the naked eye. A comparison of the appearance seen with the naked eye, and the one seen in the telescope, will help in easily finding the line corresponding with the one seen with the naked eye. The exactitude of these measurements must be within about 3′ to 6′ in azimuth and altitude, while the time should be exact within 2 to 4 seconds.

The employment of photographic apparatus is of advantage for the indication of the place as well as of the movements of the phenomenon. But only such apparatus is suitable of which the proportion of the diameter of the aperture to the focal distance is at least 1 : 4 or greater. If the proportion were smaller, the duration of exposure would have to be too long, and conse-

quently, on account of the rapid changes of the phenomenon, the details would be lost. With an apparatus of which the proportion of the aperture to focal distance is 1 : 3, the duration of exposure for the various depressions of the Sun below the horizon, under the condition that the phenomenon is bright in some degree, is as follows:

Depression of the Sun Below the Horizon.	Duration of Exposure.
°	s
9	16
10	21
11	27
12	35
13	48
14	72
15	122

Generally at the same time stars become visible on the photographic plate, through which together with the time of exposure, the direction of adjustment of the apparatus is ascertained; (that is to say: the position of the axis of the apparatus is ascertained).

With regard to the equator region, it is of great value to carefully observe the time when the luminous night-clouds pass through these regions. According to the observations made up to the present, the passage across the equator may take place between the beginning of September and the end of October, and the return, between the beginning of March and the end of April. In 20° south latitude the passage will take place from the middle of September to the middle of November, and from the middle of February to the middle of April, and in 20° north latitude, from about the middle of March to the middle of May, and from the middle of August to the middle of October. Besides, in consequence of the daily rotation of the Earth on its axis, together with the distinct movements of the Earth's atmosphere, it may be, that the passage across the equator does not take place in the simple manner here described. It does not seem to be unlikely, that the periods are not limited as exactly as stated.

Moreover, it is probable that the luminous night-clouds consist of a kind of gas, which is condensed in consequence of the lower temperature prevailing at the altitude of 82 kilometres. Upon the question regarding the kind of this gas, several other cosmical questions depend; for instance, with respect to the temperature of the air of the inter-planetary space, and the temperature of the atmosphere in the altitude of 82 kilometres, which will be answered through comparing experiments in the laboratory. For this purpose, photographs of the spectrum of sunlight

at low altitudes of the Sun, in the season in which the phenomenon of the luminous night-clouds is seen, are of great value. Such spectrum photographs should be taken in the evening, shortly before sunset, and in the morning, shortly after sunrise.

It appears, that in the northern regions of the Earth, at about 70° latititude, during the period from the middle of June, until the middle of July, an extra great accumulation of clouds takes place, which, however, because of the Sun, is constantly *above* the horizon during this time, will be hardly visible. It will therefore be of special advantage, for this region, to take spectrum photographs of sunlight at low altitudes.

The above short remarks, regarding the importance of the phenomenon, in relation to cosmical problems, will show sufficiently, that the observations necessary for the investigation of the same essentially belong in the sphere of work of astronomers and geophysicists. There can be no doubt, that the observations necessary for the solution of these problems, far exceed the province of a single institution. The request is therefore issued to all those observers who take interest in the furtherance of the questions indicated, to assist through one or the other kinds of observation indicated above, in the investigation of the luminous night-clouds.*

ROYAL OBSERVATORY, Berlin, September, 1892.

THE TOTAL ECLIPSE OF THE SUN, 1893.

JOHN KING.†

As I have been asked by some astronomers to give a description of the general appearance and climate of this part of Chile, in which a total eclipse of the sun occurs next year, I have drawn up for publication the following account:—

The eclipse takes place on April 16, 1893, at about 8.15 A. M., Chile local time, and will be seen to the greatest advantage in this part of the Province of Atacama.

At the sea coast the central line of total eclipse passes close to Chañaral 29° S. L. This is not the better known Chañaral, north of Caldera, but a small place equidistant from Coquimbo

* A publication "Die leuchtendem Nachtwolken" by O. Jesse, which may be expected within the next month, will contain details in full regarding the present state of this problem.

† British Vice Consul, Carrizal Bajo, and engineer of the Carrizal and Cerro Blanco railway.

and Carrizal Bajo. The southern limit of total eclipse is 29° 50′ S. L. just north of Coquimbo, and the northern limit 28° 10′, just south of Carrizal Bajo.

The band of total phase stretches between these two limits in a north-easterly direction, across the country, from the coast towards the rising sun. Along the central line of this band the sun will be hidden by the moon for nearly three minutes. The eclipse will be total everywhere within the limits given above, but the total phase will be shorter and shorter the nearer those limits are approached, and outside of them the eclipse will be partial.

On the accompanying map of the Carrizal and Cerro Blanco and Copiapo Railway systems I have marked the northern and southern limits, and the central line of totality.

It will be seen that the port of Carrizal Bajo, 28° 4′ S. L., is just outside the total band, but the railway connecting it with Yerba Buena intersects the central line of total eclipse 70 miles inland, and a branch to Merceditas, 60 miles inland, at an altitude sufficiently high to be above the damp and hazy atmosphere of the coast. At the points of intersection the climate is simply perfect for astronomical observations, and is also, during the month of April, delightful to live in.

The accompanying form was filled up, in compliance with a request from Amherst College Observatory, to show the cloud conditions in the inland region during the month of April this year as an indication of what might be expected during the same month next year.

I had two series of observations made, one at Mina Bronces by Mr. Martin, chemist to the works (the results of which are hereto appended), the other at Cerro Blanco by Señor Miranda, at his mine. Both reports are in every respect alike. The 10th and 27th were cloudy, all the other days absolutely clear. As the two stations are some twenty-five miles apart, these reports show that there is no local weather, and that it is only when a general atmospheric disturbance, originating in the Cordillera de los Andes, occurs that the weather is affected at these high stations.

It will be seen that there was only one day—the 27th—out of twenty-one days of observation on which the sun was not visible at eight o'clock in the morning, for on the other cloudy day—the 10th—the sun was bright at intervals.

Cloud Observations at "Mina Bronces," Chile, 1892.

Local time.				Remarks.
Day.	7:45 A. M.	8:15 A. M.	8:45 A. M.	
April 10	2	2	2	Clouds were light, allowing a slight shadow to be cast. Bright Sun at intervals.
" 11	2	0	0	Clouds were on the horizon, so that the Sun rose above them at 8 o'clock.
" 12	0	0	0	Perfectly clear sky.
" 13	0	0	0	Perfectly clear sky. Sun rose at 6:22 A. M.
" 14	0	0	0	Sun rose at 6:22 A. M.
" 15	0	0	0	Fresh wind. Sun rose at 6:23 A. M.
" 16	0	0	0	Sun rose at 6:24 A. M.
" 17	0	0	0	
" 18	0	0	0	Slight haze at sunrise. Sun rose at 6:25 A. M.
" 19	2	0	0	Bank of clouds near north-east horizon, which the Sun rose above at 8.05.
" 20	0	0	0	Sun rose at 6:26 A. M.
" 21	0	0	0	" " 6:27 "
" 22	0	0	0	" " 6:28 " Strong wind.
" 23	0	0	0	" " 6:29 " " "
" 24	0	0	0	
" 25	0	0	0	
" 26	0	0	0	
" 27	4	3	3	Haze thick at 8:15 A. M., but light at 8:45 A. M.
" 28	0	0	0	Sky got cloudy at midday.
" 29	0	0	0	
" 30	0	0	0	

KEY.

0 = "Sun entirely clear from clouds."
1 = "Clouds generally scattered."
2 = "Clouds massed about the Sun."
3 = "Sun in haze or fog.
4 = "Sun invisible in thick clouds."

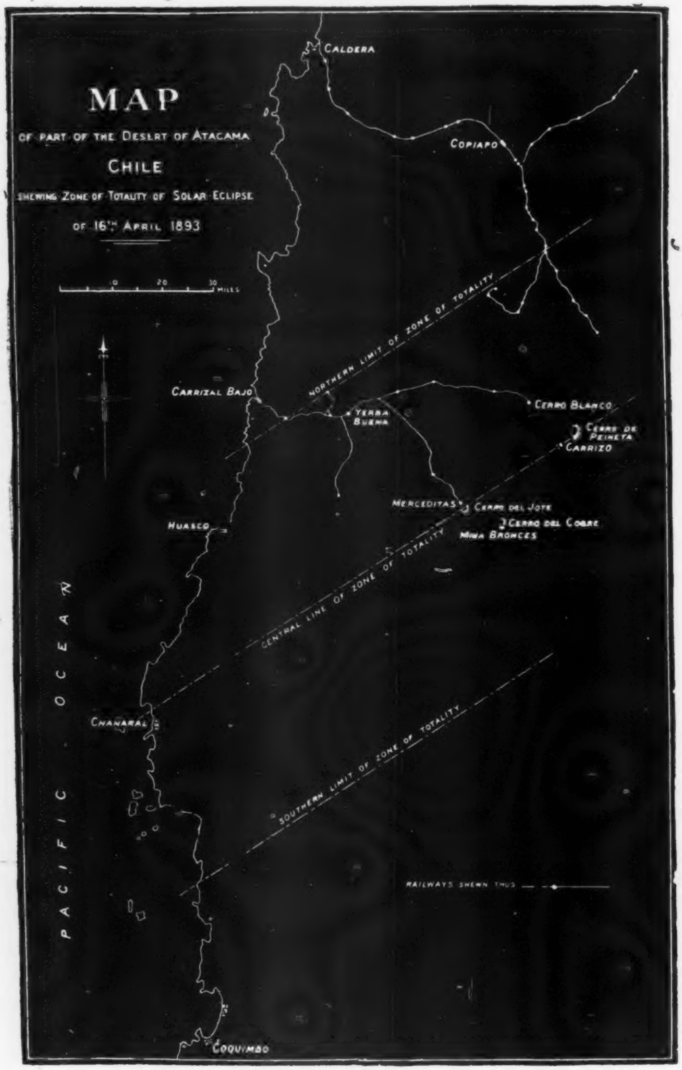
Observatory Stations.

I have marked on the map, along the central line of totality, several stations that I think suitable for observatories; the positions are only approximately correct, for I have no means of determining them accurately, but the errors, if any, cannot be great.

Undernoted are heights above sea level of some places shown on the map:—

Yerba Buena railway terminus	3,867 feet
Cerro Blanco, north hill	10,000 "
" south, Peineta	8,000 "
Carrizo, in the valley, a small farm	5,000 "
Merceditas railway station	2,900 "
Cerro del Jote	6,000 "
Cerro del Cobre	8,000 "
Lay observatory	4,000 "

Cerro de Peineta is part of Cerro Blanco; this Cerro Blanco is not part of the Andes, but a detached hill with low ground all


MAP
OF PART OF THE DESERT OF ATACAMA
CHILE
SHEWING ZONE OF TOTALITY OF SOLAR ECLIPSE
OF 16TH APRIL 1893
10 20 30 MILES
CALDERA
COPIAPO
CARRIZAL BAJO
YERBA BUENA
CERRO BLANCO
CERRO DE PEINETA
CARRIZO
MERCEDITAS
CERRO DEL JOTE
CERRO DEL COBRE
MINA BRONCES
HUASCO
CHAÑARAL
COQUIMBO
PACIFIC OCEAN
NORTHERN LIMIT OF ZONE OF TOTALITY
CENTRAL LINE OF ZONE OF TOTALITY
SOUTHERN LIMIT OF ZONE OF TOTALITY
RAILWAYS SHEWN THUS

round, and a clear view to the north-east. It is easily ascended by pack-mules.

Carrizo is not a hill, but a small farm or large garden, irrigated by a mountain stream. The advantages of this station are: nearness to the railway, a good road, and plenty of small hills of easy ascent to select from.

Cerro del Cobre is a good hill, but probably too far south. However, there are hills all the way from Merceditas that might be selected (see Mr. Martin's letter).

Serra del Jote, near Merceditas, is accessible to pack-mules half-way up, higher than which it would not be necessary to go. Moreover, it is said that the rest of the ascent is difficult. The three hills, Cerro de Peineta, Cerro del Cobre, and Cerro del Jote, can all be seen from one another.

Lay Observatory. On April 15 I went to Merceditas and stayed overnight, as I wished to find near the railway station a hill on which the sun shone at an early hour on the morning of the 16th, through some opening among the surrounding hills, and which would be suitable for ordinary lay observers who had no expensive apparatus, but who wished to see the eclipse well through a smoked or colored glass. To the south of the railway station I found a range of hills eminently suited to the purpose; at a height of 4000 feet above the sea the sun shone over a dent in the Jote at 6.40 A. M. The hill is much higher than 4000 feet, but I did not go higher. This is an excellent, well-sheltered spot, and would do well as a station for professional astronomers. I went up on horseback in forty minutes, but the ascent, from the railway station, could be easily made on foot in an hour. As I could not find any local name for this hill, I called it the Lay Observatory.

Climate.—At two o'clock in the afternoon of April 15 the temperature at Merceditas was 78° F.; this was the hottest time of the day, and it was a warmer day than usual, and at 8 P. M. the temperature was 62° F. Next morning, the 16th, I got up at two o'clock to see the comet then visible, and found the temperature was 58°; at 5 A. M. it was 56°.

Everywhere on the coast of Chile, north of Coquimbo, the sun, in the morning, is almost always obscured by a thick haze which makes the sky of a dull lead color. This haze is sometimes driven away by the sun during the forenoon, but just as often it remains all day, especially during the months of March, April and May.

The hazy morning atmosphere extends inland for a distance of

about forty miles, and up to an elevation above the sea of about 2,500 feet; beyond this distance and height the sky is almost always clear and the air dry. Standing in the early morning, on a mountain of 3,000 to 4,000 feet or higher, you looked down on a great white sea of mist covered with whiter ridges like motionless waves, and studded here and there with islands which are the mountain tops piercing through. This haze is usually gone by nine o'clock, except within about five miles of the sea.

Accommodation on the Hills.—Tents can be quickly and cheaply made with the "esteros de totora," that is, mats made of reeds. All the more temporary houses of miners and prospectors and of railway track repairers are made of these mats which are seven feet square, and may be rolled up and carried from place to place. They form an article of commerce, and cost eighteen pence each, or from eighty to ninety cents of Chile paper currency. During the month of April and part of May it is quite safe to trust to this kind of tent, but not later than the middle of May, for rain or snow sometimes falls in the end of that month.

There are no venomous reptiles in Chile, nor are there mosquitoes on these hills, and fleas cannot live at an altitude of 4,000 feet—no slight advantage.

Rain.—On the Chilian side of the Andes, in the province of Atacama, rain generally falls twice in the year: the first rain is expected in June, the next in July, each rain usually lasting two days, and always accompanied with wind from the north. As soon as the wind changes to its prevailing quarter, the south, there is beautifully clear but cold weather. From two to three inches of rain fall in the year, but sometimes less than one inch. On Cerro Blanco it usually freezes every night from July till the end of August, and some snow lies on the mountain till September. On the hillsides there are plenty of bushes and small trees for firewood, and excellent water is found in all the higher valleys.

I have heard one objection to this district for observing the eclipse, which is that as the eclipse takes place in the morning, and the sun is not high in the sky, it would be better to go farther east. This objection has no weight, on account of the extreme dryness of the atmosphere. At the mines on Cerro Blanco and the other hills everything gets dried up; Huasco raisins grow hard and rattle on one's plate like nuts; agricultural produce, such as wheat, beans and barley, brought from Southern Chile as food for man and beast at the mines, loses two per cent of its weight every month for several months, office ink bottles have to be kept tightly corked or the ink very soon dries up, chairs and

tables fall to pieces, veneer peels off, and a piano soon loses its tone. The sky is dark blue, and the sun rises white and dazzling without a trace of any other color. The hills, the rocks, and the bushes cast dark shadows, and even every pebble the size of a hazel nut casts its shadow, so that in the early morning the gravelly ground seems half wetted with a shower; one side of every pebble is in bright light, the opposite in deep shadow.

Although the eclipse would be the object of greatest interest to visitors, a few weeks might be profitably spent among the copper mines, and if any one wished to become a mine owner, plenty of mines are to be had for the asking. All the mines belong to the State. You have only to take up a mine, pay a nominal license to the government annually, and the mine is yours as long as you pay the license. There are no royalties, no surface rents and no export duties. The next thing to do is to make the mine pay, and this is sometimes done.

There is no sport in April, but after snow falls on the Cordillera, huanacos and immense flights of turtle-doves come down to feed on the lower slopes. Life, however, is never wanting. The region from Cerro Blanco southward as far as Coquimbo is the home of the fur chinchilla. It feeds on the nut of the carbon tree, *Cordia decandra* (Hook. et Arn.), and on the pea of the algarrobillo, *Balsamocarpon brevifolium* (Clos.). This bush which produces the tannin pod of commerce, thrives best far inland, on sunny, almost rainless slopes, but it must have one shower in June or July, otherwise it bears no fruit. If there be no rain for three or four years—as sometimes happens—the bushes do not die—they just wait. The same thing happens with all the other bushes; sometimes for several successive years, they are without leaves, and though the soil seems as dry as dust, whenever rain comes they show themselves full of life.

British astronomers—professional and amateur—ought not to lose the opportunity of observing under such favorable circumstances this great eclipse. I doubt if better conditions were ever offered before. The distance to come is long, but the expense is not very great, and can be exactly counted beforehand. An expedition might leave Liverpool in February by Straits of Magellan steamer, and be home again in June. Or, after the eclipse go by steamer to San Francisco or Vancouver, and thence by rail to the World's Fair at Chicago, and instead of encountering hardship and danger in some unhealthy climate, have a pleasant trip all the way.

Though horses and mules can be got here everyone should bring a saddle and bridle.

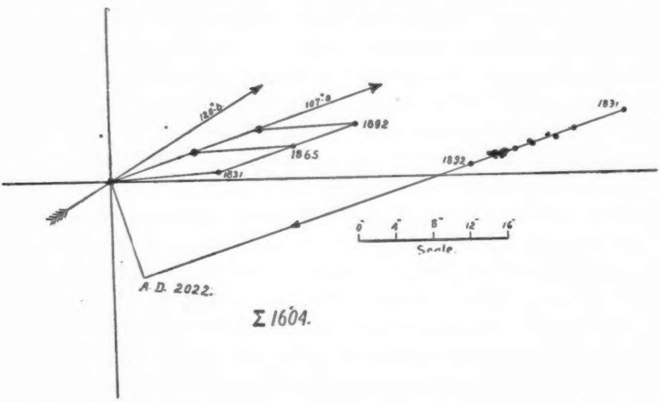
In conclusion I would impress on the members of every expedition that may come out, the importance of selecting as observing stations, places at a distance of at least 60 or 70 miles from the sea. On the other hand, the advantages of going further inland are doubtful, and as the railways go no farther, traveling would be more difficult.

Carrizal Bajo, Province of Atacama, Chile, May, 1892.

ON PROPER MOTION OF Σ 1604.

S. W. BURNHAM.

This is one of the wide triples of Struve's Catalogue. The more distant of the two companions is now much nearer the primary than it was at the time of the first measures by Struve; while the change in the other has been very small. It is well known that the apparent motion of C is rectilinear, and due to the proper motion of A. The other companion has practically the same proper motion as A, the entire change of distance in sixty years being but little more than 1″. The proper motion of the principal star as given by Stumpe is 0″.354 in the direction of 120°.6. This is probably based upon meridian observations. The micrometer measures of C give a somewhat different result.



Σ 1604.

It might be said that C may have some proper motion of its own, and that therefore the other value is not necessarily in error. While this may be the fact, it seems impropable for the reason that the difference between the two values is not a large error in meridian positions of stars to which attention has not

been specially directed. The measures of C, assuming that star to be fixed, give an annual proper motion for A of 0″.289 in the direction of 107°.8. If, however, the other value given for the movement of this star is correct, then C has a motion of its own of about 0″.1 per year in the direction of 160°. This question can be best settled by connecting A with some other star.

The following is a complete list of the measures of both companions, including my recent observations with the 12-inch refractor at Mt. Hamilton:

A and B.

	°	″		
1831.95	93.3	11.98	Struve	3n
1835.40	89.9	12 ±	Herschel II	1n
1844.34	94.8	11.01	Madler	1n
1856.40	92.8	11.75	Secchi	1n
1863.31	94.6	11.38	Hall	1n
1865.63	92.5	11.21	Dembouski	7n
1869.85	91.6	11.37	Duner	2n
1877.40	91.5	11.60	Flammarion	1n
1879.33	91.1	11.32	Burnham	1n
1879.35	89.7	11.46	Cincinnati	1n
1880.30	91.1	11.44	Pritchett	2n
1881.36	90.7	11.20	Bigourdan	1n
1883.15	91.8	11.13	Englemann	6n
1884.58	91.4	11.40	Wilson	2n
1890.35	90.3	10.37	Glasenapp	2n
1892.37	91.5	10.70	Burnham	3n

A and C.

	°	″		
1831.95	96.9	58.00	Struve	3n
1835.40	93.0	60 ±	Herschel II	1n
1856.40	95.2	50.38	Secchi	1n
1863.31	94.6	48.51	Hall	1n
1864.70	94.8	47.68	Dembouski	6n
1869.85	94.0	45.96	Duner	2n
1871.17	94.1	45.64	Dembouski	1n
1877.37	93.5	43.95	Schiaparelli	2n
1877.40	93.1	41.92	Flammarion	1n
1879.33	93.3	42.92	Burnham	1n
1879.33	93.1	43 21	Schiaparelli	1n
1879.35	93.5	43.97	Cincinnati	1n
1880.30	92.9	42.62	Pritchett	2n
1881.34	92.7	42.68	Schiaparelli	1n
1881.36	92.9	42.88	Bigourdan	1n
1882.38	93.2	42.06	Schiaparelli	1n
1883.37	93.1	41.69	Schiaparelli	1n
1883.53	92.6	41.85	Engelmann	5n
1884.37	93.0	41.53	Schiaparelli	5n
1884.58	92.3	42.00	Wilson	3n
1885.40	93.0	41.27	Schiaparelli	1n
1890.35	91.9	39.23	Glasenapp	2n
1892.37	91.9	39.19	Burnham	3n

The magnitudes of A, B and C in Struve are respectively 6.5, 9.0 and 7.8. The principal star is Virginis 59 (= Lalande 22798), and the bright companion to Lalande 22803. The three stars are found in the Argentine General Catalogue, the magni-

tudes being 7, 8½ and 8. Herschel called B "very ruddy." The nearest approach of C will be about the year 2022, when its distance from A will be about the same as the present distance of B.

CHICAGO, Nov. 10, 1892.

A FREE ESCAPEMENT WITH A PERFECTLY INDEPENDENT BALANCE OR PENDULUM.*

D. APPEL, CLEVELAND, O.

In the early part of the year 1884, while occupied with a study on free escapements, I was on March 10 of the same year led to the discovery of a new principle for a free escapement with a perfectly independent balance or pendulum with unlimited oscillations.

In common practice the transmission of power to the balance is effected directly through the escapement, whereas in the new principle the balance derives its impulse through the hair spring. This is accomplished by having the free end of the hair spring arranged to be movable. The performance of the wheel train consists in moving to and fro, at the proper moment, the free end of the hair spring at each vibration of the balance. This may be done in several ways according to the application of the escapement to chronometers, pendulum clocks or watches, or to instruments which require to be driven with precision under variable resistance, such as a heliostat or, as in the present case, to a small equatorial in which the new escapement is subject to the most severe test. For the latter purpose the new escapement is so constructed that it will easily control a considerable surplus of power without affecting its function as an excellent time-piece. This has been successfully demonstrated on a 4-inch equatorial of Warner & Swasey in June, 1890, with the partially illustrated driving clock provided with the new escapement regulated to sidereal time.

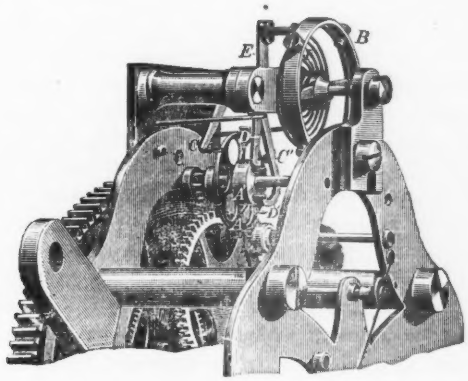
During the trial of the new escapement the 4-inch telescope, an equatorial star near the meridian could be carried bisected by the vertical wire for some time with a hardly perceptible variation of light on either side of the wire. These tests I repeated on several evenings in June, 1890, with the same results.

The driving clock, connected to the lower end of the polar axis, has been an ordinary eight-day Seth Thomas lever clock, the

* Communicated by the author.

wheel train of which was modified for an increase of power, and a wheel of forty-eight teeth was added to correct the error effected through the new escape wheel having only six instead of fifteen teeth.

The escapement shown in the illustration is constructed after one of my models of 1887 in which the escape wheel consists of a large locking wheel, A, with 6 teeth (3 on each side), and a small lifting pinion, A′, with 3 teeth, of which only 2 can be seen in the cut. The axis of the anchor (not visible) which may be considered a continuation of the balance axis, carries two rigidly connected anchors of which CC′ effects the unlocking of the wheel A, while the other anchor, DD′ during the rotation of the escape-wheel through the lifting pinion, A′, increases the tension of the hairspring, the free end of which is fastened to an extension, E, of the lifting anchor, DD′.



The illustration shows the escapement at the moment in which the balance B moves in the direction of a clock hand, having just passed her rest position, the increasing tension of the hair spring F effects a moment later the release of the locking wheel A, through the anchor arm C, at this moment the longer arm D′ of the lifting anchor is moved to the right by the lower pin of the lifting pinion A′ through the rotation of the escape wheel, increasing the tension of the hairspring. Meanwhile the balance completes her motion, and effects after passing her resting point in an opposite direction, in the same way, the releasing of the locking wheel A through the partially shown anchor arm C′ and causes the upper pin of the lifting pinion A′ to move the shorter anchor arm D to the left. The escapement is now again in the position

shown in the illustration, and as soon as the balance returns from her journey to the left, and has passed her point of rest, we have again arrived at our starting point. The same performance repeats itself at each double oscillation, without the balance being influenced by the wheel train or disturbed by the escapement during her oscillations.

THE PROPER MOTION OF THE STARS.*

W. H. S. MONCK.

In comparing the proper motions of different stars it occurred to me that it would be desirable to refer them to a common standard. When the magnitude of the star had been ascertained photometrically this was easily done on the assumption that no light is lost in transmission. The proper motion being expressed in seconds (of an arc) by multiplying it by the number whose logarithm is one-fifth of the magnitude on the photometric scale, we obtain in all instances what the motion would be if the star was brought near enough to us to appear as one magnitude brighter than the first (or of magnitude 0 on the photometric scale). I compared Herz and Strobl's revision of Auwers' Catalogue with the Harvard Photometry for this purpose and obtained the photometric magnitudes and proper motions of nearly 600 stars. The proper motions in right ascension, however, were given in seconds of time and it would have taken some labor to reduce them to seconds of an arc; and as my object was to deal with classes of stars I thought it sufficient to compare the motions in N.P.D., believing that the averages were likely to be the same in right ascension as in declination. I further extracted from the *Draper Catalogue* the spectra of all the stars which I was able to identify. In a few cases my identifications are doubtful. In many others the spectrum is marked as doubtful in the *Draper Catalogue*. I thought it best to follow its classification without regarding the notes of interrogation. The first step was to ascertain the average proper motion of the 600 stars when referred to the standard in question. Here I found that in taking an arithmetical mean the result would be much influenced by a few stars with great proper motion. Thus 61 Cygni had on my scale a proper motion of 34 seconds annually in N.P.D. which when distributed among 600 stars would raise the general average by about 0″.060. Instead of an arithmetical mean I therefore thought it better to ascertain the point at which the

stars with greater and less proper motion would be equal in number, and I found that for the entire number of the stars examined the average thus obtained was about 0″.225 annually. I may here remark that supposing the average velocity of a star towards or from the north pole to be 10 miles per second (being the average velocity in the line of sight according to Vogel) the average parallax of these 600 stars, if brought near enough to us to appear one magnitude brighter than the first, would be only about 0″.067. The arithmetical mean would be considerably greater than 0″.225, but I did not think it necessary to determine it precisely.

When, however, I examined the means for stars of different magnitudes the results were remarkable. Of 8 stars ranked in the *Harvard Photometry* as above the first magnitude only two (Rigel and Betelgeuse) have a standard motion of less than 0″.225. The average determined for the eight in the above manner is 0″.537, the arithmetical average being 0″.618. But the 15 stars between magnitudes 1 and 2 (including Aldebaran rated at 1″.00) include 13 with a motion less than 0″.225 and only two with greater motion. The average for these 15 stars determined as above is only 0″.066, and the arithmetical average 0″.103. The average standard motion of these fifteen stars in N.P.D. is consequently not more than one-sixth of that of the foregoing eight. The stars between the 2d and 3d magnitude are also far below the mean, though their motions average a little more than that of their immediate predecessors. The average determined as above is about 0″.1, or arithmetically 0″.2. In 16 cases the motion is greater than 0″.225 and in 43 less. Between the 3rd and 4th magnitudes, however, the mean is nearly realized, 89 stars according to my count being above 0″.225 and 98 below it. From the 4th to the 5th magnitudes the figures are almost identical with the foregoing, the standard motions of 87 stars being above 0″.225 and those of 97 below it. The arithmetical average for the stars of magnitude 3 to 4 is indeed greater than for magnitude 4 to 5, 27 stars giving a standard motion of over 1″ in the former case against 19 in the latter. Between the 5th and 6th magnitudes I found 74 stars above the mean against 50 below it; but probably a good many of these fainter stars owe their introduction into Auwers' Catalogue to their considerable proper motions, so that a fuller examination of the proper motions of all stars between the 5th and 6th magnitudes might lead to a different result. The same remark applies more strongly to the small number of stars below the 6th magni-

tude which the catalogue contains. It will be seen, at all events, that there are two exceptions to the steady increase of (standard) motion as the stars become fainter. One is afforded by the eight brightest stars in the catalogue and the other by the stars comprised between the 4th and 5th magnitudes. I may add that in considering the quantities of proper motion only and disregarding their directions, it seems to me that errors of observation or computation will necessarily increase the average motions of very faint or rather very distant stars. Such errors will assign small motions of approach or recession where the motion is really insensible, and these small motions may be considerably increased by multiplying them by the number whose logarithm is one-fifth of the photometric magnitude as already explained. I may remark that taking the average standard proper motion in N.P.D. of a second magnitude star at 0″.100 the average parallax on the assumption of an average velocity of 10 miles per second would be only 0″.03; but this being the parallax on the assumption that the star was brought near enough to appear two magnitudes brighter than it is, the actual average would be only 0″.012. The recently published Oxford observations give an average parallax nearly 5 times as great as this; according to which the average velocity of a second magnitude star to or from the north pole is only about 2 miles per second. The average velocity in the line of sight differs from this in rather a startling manner.

My main object, however, was to compare the standard motions of stars with different types of spectra. The result of this comparison can be best presented in a tabular form, but I have omitted spectra which occur so rarely that the results are unreliable.

Spectrum (Draper Catalogue).	Standard Motions. over 1″.0	0″.5 to 1″.0	0″.3 to 0″.5	0″.2 to 0″.3	0″.1 to 0″.2	under 0″.1	Total.
A	9	28	48	32	40	77	234
B	0	1	0	1	9	17	28
F	29	10	10	2	12	12	75
G	5	1	1	1	2	9	19
H	11	8	8	5	6	15	53
I	10	7	6	5	11	6	45
K	10	10	15	9	19	31	94
M	0	8	6	5	6	6	31

It is evident at a glance that the standard motions of the solar stars (spectra F, G, H, I and K) are far in excess of those of the Sirians (spectra A and B). But the subdivisions show other remarkable differences. The standard motions of stars with spectrum B fall far short of those with spectrum A. In fact, the

average motion for stars of this type, determined in the way already indicated, is only 0″.052, the arithmetical average being 0″.098. The corresponding averages for spectrum A are between three and four times as great as this. Again, the stars with spectrum F (with which the small number of stars with spectrum E should probably be classed) have, on the average, much greater proper motion than the other stars of the solar type. In more than one-half of them, the standard motion exceeds half a second annually, in which respect they stand alone, and nearly three times as many of them have a standard motion of over one second annually as of the more numerous class of solar stars with the spectrum K. I have elsewhere proposed to call stars with the former type of spectrum Capellan, from the brightest star which possesses it, and to call stars of the latter type Arcturian for a similar reason. Stars with the spectra G, H and I appear to agree better with the Arcturian than with the Capellan class. Only four stars in the Catalogue have spectra of the type E and of these, two have standard motions of more than one second annually, thus agreeing with the Capellan stars. Stars with spectra of the third type (M) hold an intermediate position between the Sirians and Solars as regards proper motion. The average is not very different from that for the class K. No Sirian star has a standard proper motion of more than 2″ in N. P. D. and only 4 stars of the type K attain that figure, but it is attained by no less than 23 stars with the spectrum F. I think I am justified in concluding that the Capellan type (which I believe approaches most nearly to that of the Sun) is the predominant one among our nearest neighbors. Otherwise, stars with this type of spectrum must move through space with much greater velocity than the others. This latter theory is rendered improbable by the extent to which the motions of these stars appear to be affected by the Sun's motion in space. Thus, of the 29 Capellan stars with standard motion of more than one second, 19 are approaching the North Pole and only 10 receding from it. This proportion agrees pretty well with the other stars whose motion exceeds the same limit, but for the total number of stars in the Catalogue the preponderance is considerably less. The motions of the same stars in right ascension points to a similar result. Assuming the right ascension of the Sun's goal to be 18^h the effect of the Sun's motion will be to diminish the Right Ascension of stars between 6^h and 18^h and to increase it between 18^h and 6^h. I find that the former interval contains 17 and the latter 12 of the 29 stars under consideration. The latter 12 are divided equally as regards increasing or diminishing R. A., but 13 of the 17 in the other interval have motions in diminishing R. A. A closer agreement would have been obtained by taking the R. A. of the Sun's goal at $17^h\ 30^m$. My conclusion is further confirmed by the large proportion of Capellan stars among binaries for which orbits have been computed; for in this case if we reject the explanation by greater nearness, our alternative is not greater velocity but greater mass. Further investigation with more extensive Catalogues is no doubt requisite, but I think I have made out a fair case for my conclusion that, great

as the distances between the components may be, the Sun forms one of a group or cluster of stars in which the predominating type of spectrum is similar to its own. With regard to the recently published parallax researches at Oxford, they seem to me hardly to bear out the sanguine expectations formerly entertained as regards the photographic method. The results, however, are rather favorable to my conclusion. The average parallax of the 21 second-magnitude stars measured at Oxford is 0″.056. They consist of 12 Sirian stars, 8 solars and 1 with a peculiar spectrum. The average for the 8 solar stars taken separately is 0″.071, which is considerably in excess of that for the Sirians. It so happens, however, that of the 8 solar stars only one belongs to the Capellan type. Its parallax is 0″.0867. Only one of the 21 stars has a standard motion of more than one second. It has the largest parallax of any in the list, viz., 0″.128. Six of the solar stars have the spectrum K and one the spectrum L which may be also classed as Arcturian.

The nearness of the Capellan stars which seems to be thus established is a nearness relatively to stars of the same magnitude but with different types of spectrum. Researches on binary stars seem to establish that this is not due to smaller average mass, and it would therefore appear that these stars are of the dullest or least light-giving class—more so not only than the Arcturian stars but than those of the type of Antares or Betelgeux. The Sun as a Capellan star may therefore be expected to give a small amount of light relatively to its mass when compared with most of the fixed stars. The comparisons hitherto made point in this direction.

ROBERT GRANT.*

In Robert Grant, who at the ripe age of seventy-eight died at the place of his birth, Grantown-on-Spey, on October 24, 1892, science loses one of her ablest historians. His education was interrupted by a serious illness, which confined him to his bed from his fourteenth to his twentieth year. With surprising energy, however, on his recovery he set about the study of mathematics and the acquisition of ancient and modern languages. After studying for a time at King's College, Aberdeen, he went to London to collect materials for a history of physical astronomy. Thence he proceeded to Paris in 1845, where for two years he attended the lectures of Arago at the Observatory, and those of Leverrier and others at the Sorbonne. Returning to London, he lost little time in beginning the great work with which his name will always be associated. It was published in numbers, the first of which appeared in September, 1848, but it was not until March, 1852, that the whole work was issued. It bears the title "History of Physical Astronomy from the Earliest Ages to the Middle of the Nineteenth Century, comprehending a detailed account of the establishment of the Theory of Gravitation by Newton, and its development by his successors; with an exposi-

* *Nature*, Nov. 10, 1892.

tion of the progress of research in all the other subjects of Celestial Physics." Most completely do the contents of the volume fulfil every expectation raised by this comprehensive programme. The fame of its author was at once established. Four years later he received from the hands of the late Mr. Manuel J. Johnson, President of the Royal Astronomical Society, the gold medal, then for the first time awarded for literary service to astronomical science. One paragraph of the address delivered on that occasion may here be quoted as characterizing most justly the work as well as its author: "Throughout the book no one can fail to be struck with the rare skill, integrity, and discernment the author has displayed in tracing the successive stages of progress; or with the scrupulous care he has taken to assign to each of the great men whom he reviews their proper share in the common labor. Nowhere is this more conspicuous than in the discussion relative to the discovery of the planet Neptune. By a simple narration of facts he has placed the history of that great event in so clear and so true a light, that I believe I am not wrong in saying he has gained an author's highest praise under such circumstances—the approval of both the eminent persons concerned." Even now, forty years after its publication, the "History" has lost none of its value as a mine of information, and as a delightful guide to those who desire to make a closer acquaintance with the astronomers of the past as well as their works.

For some time Mr. Grant edited the "Monthly Notices" of the Royal Astronomical Society, and was a member of their Council. In conjunction with the late Admiral Smyth, he translated and edited Arago's "Popular Astronomy" (2 vols. 1855 and 1858). Meanwhile his health had so far improved that in 1858 he was able to go through a course of observational astronomy at Greenwich Observatory. In the following year, on the death of Professor J. Pringle Nichol, he was appointed Professor of Astronomy, and Director of the Observatory in the University of Glasgow.

As a member of the party that went to Spain in the troop ship *Himalaya*, to observe the total solar eclipse of July 18, 1860, Professor Grant from his station near Vittoria, had the satisfaction of seeing a portion of the chromosphere, the existence of which as a thin layer enveloping the photosphere he had abundantly demonstrated in the winter of 1850-51, from a discussion of all the observations extant ("History," pp. 395, 396). It can excite no surprise that Professor Grant assumed the red layer and also the prominences to shine by reflected light when it is recollected that the Sun's light and heat were then supposed to originate wholly in the photosphere, while the nucleus was thought to be so cool as possibly to be habitable. When Professor Grant took charge of the Glasgow Observatory the only useful instrument he found was the transit-circle by Ertel & Son of Munich, but through the liberality of a few friends, chiefly in Glasgow, a nine-inch Cooke equatorial was added to the Observatory some years afterwards. After thoroughly testing the transit-circle the

new director commenced a series of observations of Mercury, Neptune, the minor planets, and a selection of stars from the British Association Catalogue. Gradually, however, his attention was concentrated entirely on the stars, the list being correspondingly expanded. The observations of planets were communicated from time to time to the *Astronomische Nachrichten* or to the *Monthly Notices.*

The stellar observations were published at the expense of her Majesty's government in 1883 in the well-known "Catalogue of 6415 Stars for the epoch 1870, deduced from observations made at the Glasgow University Observatory during the years 1860 to 1881, preceded by a synopsis of the Annual Results of each star arranged in the order of Right Ascension."

In the introduction will be found a discussion of the Proper Motions of 99 stars. A very complete and appreciative review of this work from the pen of Professor Auwers of Berlin appeared in the *Vierteljahrsschrift der Astronomischen Gesellschaft* (19 Jahrgang). The Glasgow star places were at once looked on with confidence by the numerous observers of comets and minor planets. One point connected with the Catalogue deserves special attention, viz., that, although the observations from which it is derived extend over a space of twenty-one years, the work appeared within two years of the close of the series. This promptitude excites the greater admiration when we learn that, exclusive of Professor Grant's personal share in the work, no less than thirteen young assistants at various times took part in the observations, and two others in the computations. Many of these personal changes, each of which brought its quota of extra work to Professor Grant were no doubt in some measure due to the smallness of the allowance provided for assistance, viz., £100 per annum. Professor Grant, however, was the last man to waste his energies in useless complaint, and dismisses this point with the remark that "in recent years the work of scrutinizing, reducing to a common epoch, and combining together the vast mass of the observations of the catalogue, extending over a period of more than twenty-one years, has pressed very heavily upon the slender resources of the observatory." The important time service of the City of Glasgow was originated by Professor Grant some thirty years ago, and continues in operation up to the present moment. In 1855 he received from the University of Aberdeen the degree of M. A., followed by that of the honorary LL. D. in 1865 in which latter year he was elected a Fellow of the Royal Society of Londón. For three years he presided over the Philosophical Society of Glasgow, to whose proceedings he made various contributions. It may also be noted that among his writings are two remarkable letters proving beyond a shadow of doubt the spurious character of the pretended Pascal correspondence. These letters were printed in the *Comptes Rendus* by special permission of the French Academy.

In manner Professor Grant was singularly vivacious, and to the last he greeted with the warmest enthusiasm every fresh discovery in the science to which is life was devoted. R. C.

Astro-Physics.

THE MOTION OF NOVA AURIGÆ.*

W. W. CAMPBELL.

My observations of the position of the chief nebular line in Nova Aurigæ's spectrum show a progressive increase of wave-length after September 7. Satisfactory observations made the last two nights fully convince me that the variation is real. It is probably the result of orbital motion. The following measures have been made recently, in addition to those already published in Astronomy and Astro-Physics:

	Oct. 19.	Nov. 2.	Nov. 3.
Grating, 1st order	5004.3	5004.32	5005.01
Grating, 2nd order	5004.3	5004.34	5004.39
Compound prism	5002.8	5004.49	5004.61
	5003.8	5004.38	5004.67

The measures of Oct. 19 were made with great difficulty, and are entitled to small weight. The results obtained with different dispersions are about equal in weight. The adjustments of the instrument for the Nov. 2 and 3 observations were tested by measuring the velocity of Venus. The observed velocity, using the second order grating, was + 7.7 miles per second. The computed velocity, from Nautical Almanac data, was + 7.4 miles.

The table below contains the wave-lengths of the chief nebular line resulting from the several nights' observations, together with the corresponding velocity of approach, in miles per second.

Date.	λ.	Velocity.
1892, Aug. 20	5003.6	— 128
21	3.7	125
22	3.7	125
23	3.1	147
30	2.4	173
Sept. 3	2.4	173
4	1.9	192
6	2.1	184
7	1.9	192
15	2.2	180
22	2.5	169
Oct. 12	3.6	128
19	3.8	121
Nov. 2	4.4	99
3	4.7	— 87

A few of the earliest measures were made with a dense 60° prism, and must be given smaller weight; however, tests made

* Communicated by the author.

by me upon known intervals in comparison spectra have shown that surprisingly accurate results can be obtained with that prism.

A photograph of the Nova's spectrum taken October 19 shows additional lines at λ 438, λ 426, λ 423 and λ 410, making eighteen thus far observed. On account of the wide slit employed the wave-lengths are reliable to three places only. The line at λ 438 exists also in the Orion Nebula spectrum. That at λ 410 is strong and is probably Hδ. A very faint trace at λ 397 is probably H. There were lines near all of these in the February spectrum of the new star.

MT. HAMILTON, 1892, Nov. 4.

NOTE ON THE REVIVAL OF NOVA AURIGÆ.*

WALTER SIDGREAVES.

Mr. Campbell's paper in the October number of ASTRONOMY AND ASTRO-PHYSICS has renewed our interest in the faded star that was new and bright in the first months of the year.

The searching analysis of its light, carried on at Mt. Hamilton in August and September, has enabled Mr. Campbell to give us a list of lines of what may be called the new spectrum of Nova Aurigæ. It is a valuable contribution to the history of the star; but it adds to our perplexity, and warns us against reading it wrongly rather than helps us to read it aright.

The three most prominent lines of the new spectrum are given at λλ 5003, 4953 and 4858, these figures being the means of 16; 6 and 7 measures respectively and their relative intensities are quoted at 10, 3 and 1. They have been identified as undoubtedly the three nebular lines, shifted five-tenth metres to the violet side.

In accepting these values as comparable with those obtained from the star in its greater brilliancy, we must make great allowance for the changed conditions of spectroscopic analysis. The supply of light from the star at the tenth magnitude cannot offer the same means for accurate measurement as were placed at our service by the more energetic radiation of its earlier life. But if the wave-lengths quoted by Mr. Campbell are the true positions of the lines on the spectrum band, they must be new lines; for their relative positions are not those of the green triplet of the earlier spectrum, or of any other three in this region. The wave-

* Communicated by the author.

length interval between the first and third, taken from Dr. Crew's measures on the 10th and 13th of February, is 155 $\mu\mu$, and the August measures give 145 $\mu\mu$ separation; while the middle line has no better representative on the first spectrum than a very faint line at 4970 observed by Mr. Campbell, or a possible broad line at 4956 noted on one of the Stonyhurst plates, but considered too uncertain to be admitted into the list of lines.

Wave-lengths of bright lines of Nova Aurigæ, 1892.

Stonyhurst February.		Lick August.			Stonyhurst February.		Lick August.		
No.	Wave-length	Wave-length	Intensity	No. of Obs.	No.	Wave-length	Wave-length	Intensity	No. of Obs.
1	5895				22	4529			
2	5734	5750	1	4	23	4517			
3	5676				24	4500			
4	5631				25	4487			
5	5612				26	4470	4466	0.1	1
6	5564	5570	0.2	1	27	4446			
7	5527				28	4417			
8	5369				29	4394			
9	5334				30	4380			
10	5310				31	4364	4358.8	0.8	6
11	5273	5268	0.3	1	32	4343	4335.9	0.1	1
12	5230				33	4312			
13	5196				34	4298			
14	5167				35	4271			
15	5016	5002.8	10	9	36	4245			
16	4922	4953.3	3	6	37	4232			
17	4861	4857.7	1	7	38	4177			
18	4664	4681.3	0.4	5	39	4135			
19	4626	4630.8	0.7	4	40	4101			
20	4583				41	3968			
21	4551								

In the foregoing table the lines of the new spectrum are placed opposite the nearest corresponding lines found on the Stonyhurst photographic plates of the earlier spectrum of February. The columns of *Intensity* and *Number of Observations* refer to the new spectrum of August. The Stonyhurst list of lines is taken from the last column of the table of wave-lengths as given in my paper for the Memoirs R. A. S., now at the press. The wave-lengths are quoted for the centres of the broad lines, each reading being the mean of the marginal measures of the line. They are independent of any shift of the spectrum due to radial velocity of the star, each line having its wave-length assigned with reference to the centre of the broad F line as the supposed true position of λ 4861 of the bright line star, and under the supposition that all

the bright lines are given by the same star. This relation was secured, as described in the Memoir, by setting the plate on the micrometer stage with the centre of the line F adjusted to the scale division that corresponds to the wave-length 4861 of the interpolation curve. But the wave-lengths quoted in the table will be found to differ a little from those of the map of the spectrum in the same Memoir; the differences being according to a final correction there fully explained.

The figures give their own verdict upon the later spectrum of the star; viz., that its lines cannot all be revivals of the older ones. And the question then becomes: to what star do the new lines belong? The three chief nebular lines, as found at Mt. Hamilton, with a shift of 5 tenth metres to the violet side, cannot belong to the bright line star of February and March, which was rushing away from us at a velocity too high and too constant to admit of its wheeling round to come back in August at the speed of nearly 180 miles in the second. We cannot, on the other hand, suppose the dark line star to have changed its dress so far as to display the characteristic colors of a planetary nebula. And we are therefore driven either to admit the presence of a third rushing star, against the enormous improbability of such a gathering, or to fall back upon the local disturbances of one, for the origin of the complicated spectrum. Mr. Campbell's remark "that the relation of this spectrum (of August) to the earlier one of February is not apparent," is the truth. But we venture to add that his discovery strengthens the probability in favor of the one-star-origin of the spectrum.

STONYHURST OBSERVATORY, Lancashire, Oct. 25, 1892.

ON THE APPLICATION OF INTERFERENCE METHODS TO SPECTROSCOPIC MEASUREMENTS.*

ALBERT A. MICHELSON.

The theoretical investigation of the relation between the distribution of light in a source, as a function of the wave-length, and the resulting "visibility curve" has been given in a paper bearing

* *Philosophical Magazine*, Sept. 1892.

I take this opportunity of presenting my acknowledgments and thanks to the Smithsonian Institution for the funds necessary to carry out this research; to the Clark University for the facilities it has placed at my disposal; and especially to Mr. F. L. O. Wadsworth, Assistant in Physics of Clark University, for the valuable services he has rendered and his unflagging zeal in furthering this investigation.

the same title as the present one in the *Philosophical Magazine* for April 1891.

The physical definition of "visibility" there adopted is

$$V = \frac{I_1 - I_2}{I_1 + I_2},$$

in which I_1 is the intensity at the centre of a bright interference-band, and I_2 the intensity at the centre of the adjoining dark band. In order to interpret the actual curves obtained by observation of interference-fringes, it is first necessary to reduce the results of the eye-estimates of visibility, which may be designated by V_e, to their absolute values as above defined.

For this purpose two quartz lenses, one concave and the other convex, and of equal curvatures, were mounted with their crystalline axes at right angles to each other between two Nicols. Under these conditions a series of concentric interference-rings appeared. If α be the angle between the principal section of the polarizer and the axis of the first quartz, and ω the angle between the axis and the analyser, the intensity of the light transmitted will be

$$I = \cos^2(\omega - \alpha) - \sin 2\alpha \sin 2\omega \sin^2 \pi \frac{\kappa(t_1 - t_2)}{\lambda},$$

where t_1 is the thickness through the first quartz and t_2 that through the second. If the analyser and polarizer are parallel, $\omega = \alpha$, and

$$I = 1 - \sin^2 2\alpha \sin^2 \pi \frac{\kappa(t_1 - t_2)}{\lambda},$$

whence $I_1 = 1$, and $I_2 = 1 - \sin^2 2\alpha$,

and $$V = \frac{I_1 - I_2}{I_1 + I_2} = \frac{1 - \cos^2 2\alpha}{1 + \cos^2 2\alpha}.$$

This curve, together with the mean of a number of eye-estimates, is given in fig. 2, Plate XLII. From these the following tableof corrections may be obtained:—

V_e.	Cor.	V_e.	Cor.
.00	.00	.55	− .12
.05	+ .03	.60	− .14
.10	+ .04	.65	− .15
.15	+ .03	.70	− .16
.20	+ .02	.75	− .16
.25	.00	.80	− .14
.30	− .03	.85	− .13
.35	− .05	.90	− .11
.40	− .07	.95	− .08
.45	− .08	1.00	.00
.50	− .10		

The curves show a general tendency to estimate the visibility

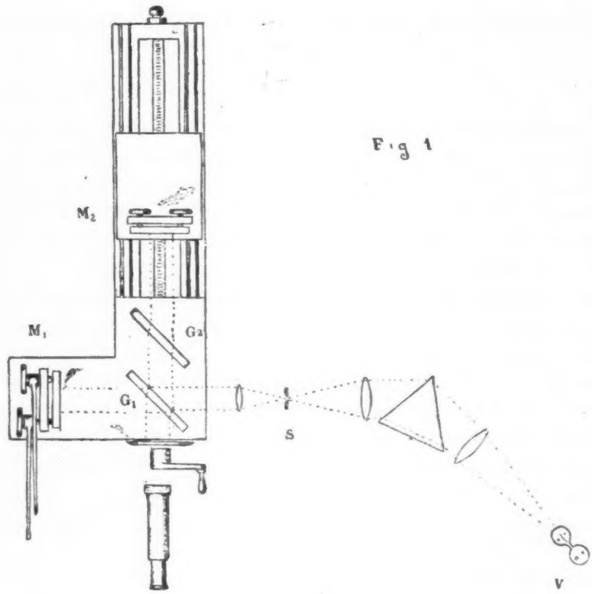


Fig 1

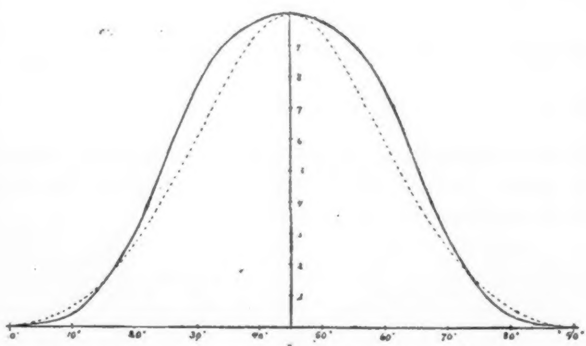


Fig 2

Equation Dot'd Curve:— $V = \frac{1 - \cos^2 2a}{1 + \cos^2 2a}$

Full Curve— Eye Estimates — V_e —

PLATE XLII.

too high when the interference-bands are clear, and too low when they are indistinct. This tendency may be modified by a number of circumstances: thus, it increases with the refrangibility of the light used; it is greater when the field contains a large number of bands than when there are but few; it is greater while the visibility-curve is falling than when it is rising; it does not seem to be greatly affected by the intensity of the light; finally, it varies on different occasions and with different observers. Notwithstanding these disturbing causes, the result, after applying the correction, will rarely be in error by more than one-tenth of its value, and ordinarily the approximation is much closer than this.*

As stated in Part I of this paper, the observations necessary to construct the visibility-curves, from which the distribution of

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* The formula for visibility deduced in the preceding paper is

$$V^2 = \frac{C^2 + S^2}{P^2},$$

in which

$$C = \int \varphi(x) \cos kx dx,$$

$$S = \int \varphi(x) \sin kx dx,$$

$$P = \int \varphi(x) dx,$$

$$k = 2\pi D,$$

$$D = \text{Difference in path},$$

and $\varphi(x)$ represents the distribution of light in the source.

In this expression no account was taken of the effect of extraneous light, and it was assumed that the two interfering pencils were of equal intensities. It can be shown that the error due to both these causes tends to lower the visibility; but in either case the correct values may be obtained by multiplying by a constant factor.

In the first case, let e be the intensity of the extraneous light, and V' the resulting visibility; then, by definition,

$$V' = \frac{(I_1 + e) - (I_2 + e)}{(I_1 + e) + (I_2 + e)} = \frac{I_1 - I_2}{I_1 + I_2 + 2e}; \text{ or if } \frac{2e}{I_1 + I_2} = r, \; V' = \frac{I_1 - I_2}{(I_1 + I_2)(1 + r)}$$

whence $V = (1 + r)V'$.

In the second case, let ρ be the ratio of intensities of the interfering pencils, then it can readily be shown that the resulting intensity is

$$I = (1 + \rho^2)P + 2\rho(C \cos \vartheta - S \sin \vartheta),$$

and hence the visibility is

$$V'' = \frac{2\rho}{1 + \rho^2} \frac{\sqrt{C^2 + S^2}}{\rho},$$

whence $V = \dfrac{1 + \rho^2}{2\rho} V''$.

If the interfering pencils differ by 25 per cent, the factor $\dfrac{1 + \rho^2}{2\rho}$ differs from unity by about 4 per cent: so that, in most cases, this cause of error may be neglected.

light in any approximately homogeneous source is to be deduced, may be made with any form of interference apparatus which allows a considerable alteration in the difference of path between the two interfering streams of light.

The apparatus actually employed for this purpose was designed for the comparison of wave-lengths, and while admirably adapted for the observation of visibility-curves, it contains many parts not necessary for this use. Fig.1. Plate LXII presents the plan of an arrangement which, while showing all the essential parts, is much less complicated. Starting from V, a vacuum-tube containing the substance whose radiations are to be examined (and which is usually enclosed in a metal box in order that it may be raised to any required temperature), the light is analysed by one or more prisms forming a spectrum from which any required radiation may be separated from the rest by passing through the slit S.*

The light from S is rendered nearly parallel by a collimating lens, and then falls on a transparent film of silver, on the surface of the plane parallel plate G_1.† Here it divides, part being transmitted to the fixed plane mirror M_1 and part reflected to the movable mirror M_2. These mirrors return the light to the silvered surface, where the first part is reflected and the second transmitted; so that both pencils coincide on entering the observing-telescope.‡

A little consideration will show that this arrangement is, in all respects, equivalent to a film or plate of air between two plane surfaces. The interference phenomena are, therefore, the same as for such an air-plate.

The theory of these interference-bands has been given in an article entitled "Interference Phenomena in a new form of Refractometer," *Philosophical Magazine* for April, 1882. As is there

* In the case of close groups of lines, the image of the source is first thrown on a slit; otherwise the lines at S would overlap.

† The light entering the telescope is a maximum when the thickness of the silver film is such that the intensity of the transmitted light is equal to that of the reflected light. The silvering has another important advantage in diminishing the relative intensity of the light reflected from the other surface. Indeed, for this purpose it is advisable to make the film heavier; even so thick that the reflected light is twice as bright as the transmitted. This does not affect the ultimate ratio of intensities of the interfering pencils—for what is lost by transmission on entering the plate G_1 is made up by reflection on leaving it, the effect being simply to diminish somewhat the whole intensity. Another advantage of the thicker film is that it can be made uniform with far less difficulty than the thin film. It may be mentioned that with this form of instrument the interference-fringes in white light present a purity and gorgeousness of coloration that are surpassed only by the colors of the polariscope.

‡ The second plane parallel plate G_2 is made of the same thickness as the first, and is required to equalize the optical paths of the two pencils.

shown, the projections of the bands are, in general, conic sections, the position of maximum distinctness being given by the formula

$$P = \frac{t_0}{\tan \varphi} \tan i \cos^2 \theta,$$

in which t_0 is the thickness of the equivalent air-plate, where it is cut by the axis of the telescope, φ, the inclination of the two surfaces, θ and i, the components of the angle of incidence parallel and perpendicular respectively to the intersection of the surfaces, and P, the distance of the plane of maximum distinctness from the surfaces. If θ be small the variations of P with θ may be neglected, and we have then

$$P = \frac{t_0}{\tan \varphi} \tan i,$$

or with sufficient accuracy,

$$P = \frac{t_0}{\varphi} i.$$

From this it will be seen that the focal plane varies very rapidly with i, so that, unless $\varphi = 0$, it is impossible to see all parts of the interference-bands in focus with equal distinctness. If, however, $\varphi = 0$, that is, if the two surfaces are strictly parallel, then $P = \infty$, and if the observing-telescope is focused for parallel rays, all parts of the bands are equally distinct. Under these circumstances the interference-fringes are concentric circles, whose angular diameter is given by

$$\cos \vartheta = \frac{\varDelta}{2t_0}.$$

If for $\varDelta$ we put $2t_0 - n\lambda$, and for $\cos \vartheta$ its approximate value $1 - \frac{\vartheta^2}{2}$, we have

$$\vartheta_n = \sqrt{\frac{n\lambda}{t_0}}.$$

In order to obtain an idea of the order of accuracy required in this adjustment, suppose the angle ϑ to be so small that its influence on the distinctness may be neglected. The intensity at the focus of the observing-telescope will be

$$I = \int\int \cos^2 \tfrac{1}{2} \varkappa \varDelta dx dy, \text{ where } \varkappa = \frac{2\pi}{\lambda}.$$

If the aperture be a rectangle whose height is $2b$, and width $2a$,

$$I = 2b \int_{-a}^{+a} \cos^2 \tfrac{1}{2} \varkappa \varDelta dx.$$

But $$\varDelta = 2(t_0 + \varphi x),$$

whence $$I = 2b\left(a + \cos 2\varkappa t_0 \frac{\sin 2\varkappa\varphi a}{2\varkappa\varphi}\right).$$

The maximum value of I is

$$2b\left(a + \frac{\sin 2\varkappa\varphi a}{2\varkappa\varphi}\right),$$

and the minimum value is

$$2b\left(a - \frac{\sin 2\varkappa\varphi a}{2\varkappa\varphi}\right),$$

whence $$V = \frac{\sin 2\varkappa\varphi a}{2\varkappa\varphi a}.$$

In attempting to verify this formula by actual observation, one is met by the difficulty that all parts of the bands are not in focus at the same time, the right and left bands being more distinct than the central one, to which attention ought to be directed. Notwithstanding the rather rough character of the observations, the results agree fairly well with theory. If φ_0 is the ratio of the wave-length to the width of the rectangular aperture, the above formula becomes

$$V = \frac{\sin 2\pi\varphi/\varphi_0}{2\pi\varphi/\varphi_0},$$

from which the second column in the following table was calculated:

φ/φ_0	V (calc.)	V (obs.)
0.0	1.00	1.00
.1	.94	.94
.2	.75	.73
.3	.50	.40
.4	.24	.13
.5	.00	.09
.6	.15	.10
.7	.22	.09
.8	.19	.07
.9	.15	.05
1.0	.00	.04

From this table it appears that if the visibility is to be estimated by observations with a telescope of 12 millim. aperture (or with a circular aperture about one-fourth greater), an error in the adjustment of the surfaces of a second of arc would produce a diminution of 4 or 5 per cent in the visibility. Accordingly, if the ways on which the mirror-carriage moves are not true to this degree, it is necessary to make the adjustment for every observation.

This can be done with very great accuracy by moving the beam of light from side to side and adjusting the mirror until

there is no perceptible alteration in the size of the rings. Since the admissible error in adjustment is inversely proportional to the aperture, the observations may be facilitated by making this as small as possible if there be light to spare. This is all the more necessary for the same reasons, if the surfaces be not true. However, the error due to this source may be easily corrected (since all the observations are affected alike) by multiplying by a constant factor.

In order that the visibility-curve may extend as far as possible, it is necessary that the vapor should be very rare. Accordingly, in all but a few cases to be mentioned later, the substance to be investigated was enclosed in a vacuum-tube, which was previously heated to drive off any moisture or occluded gases.

The vapor was rendered luminous by the discharge from the secondary of a large induction-coil, whose primary current was interrupted by a rotary break attached to the armature of an electric motor, making about 20 to 30 breaks per second. The steadiness of the light thus obtained was far greater than with the ordinary Foucault interrupter. Probably it would have been still more satisfactory to use an alternating dynamo properly wound to give a strong current with comparatively few alternations.

The box surrounding the vacuum-tube was heated just sufficiently to give a steady bright light, and the temperature then kept as nearly uniform as possible. This temperature was usually taken to represent that of the vapor within the tube. This is, of course, only a rough approximation to the truth; and in some cases the estimate was much too low.

As it was not intended to include in the present work an elaborate study of the effect of temperature, this matter was not of great consequence. It may be suggested, however, that a very much closer approximation to the real temperature could be obtained by winding a platinum wire about the capillary portion of the tube, and deducing the temperature from the variation of its resistance. A preliminary experiment in which a platinum wire passing through the tube and heated by a current until the platinum spiral outside the tube was raised to fixed temperatures, would give a means of deducing, from the indications of the spiral, the true temperature within the tube.

These adjustments being effected, the screw of the "wave-comparer" was turned to zero; that is, till there was no difference of path between the interfering pencils. At this point the visibility should be as great as possible, and was accordingly

marked 100. The screw (of 1 millim. pitch) was then turned through one turn, thus giving a difference of path of 2 millim., and the visibility again estimated, and so on. The curve was then drawn, giving the estimated visibility for each 2 millim. difference of path; and this was corrected for the personal equation, as before described.

Hydrogen.

The full curve in fig. 3 *b*, Pl. XLIII, represents such a curve for the red hydrogen line* at a pressure of about 1 millim. and a temperature of about 50° C.

The dotted curve represents

$$V = 2^{-X^2/19^2} \cos \cdot 7/30.\dagger$$

It follows that the visibility-curve is practically the same as that due to a double source, whose components have the intensity ratio 7 : 10, and in each of which the light is distributed according to the exponential law, expressed by the first term.

The formula for a double source, where the components are similar, is

$$\bar{V}^2 = \frac{1 + r^2 + 2r \cos 2\pi \frac{X}{D}}{1 + r^2 + 2r} V^2,$$

in which D, the period of the curve, is inversely proportional to the distance between the components.

But $D = N\lambda_1 = (N+1)\lambda_2$, whence

$$\alpha = \lambda_1 - \lambda_2 = \frac{\lambda^2}{D}.$$

Hence, in the present instance we have for the distance between the components of the red hydrogen-line

$$1/30 \times (6.56 \times 10^{-4})^2 = 1.4 \times 10^{-8} \text{ millim.}$$

or 0.14 division of Rowland's scale.

Again, if δ be the "half-width" of the spectral line (the value of x when $\varphi(x) = \frac{1}{2}$), then

$$\varphi(x) = 2^{\frac{-x^2}{\delta^2}}, \text{ and } V = e^{-\frac{\pi^2 X^2 \delta^2}{l^2}}.$$

* The hydrogen was prepared by dropping distilled water upon sodium amalgam, and allowing the gas to pass through sulphuric acid into the vacuum-tube, which was repeatedly exhausted until the spectrum of hydrogen was nearly pure.

† As frequent use is to be made of the function

$$\sqrt{\frac{1 + r^2 + 2r \cos 2\pi \frac{X}{D}}{1 + r^2 + 2r}},$$

it will be abbreviated to the form cos r/D.

If Δ be the value of X for $V = \frac{1}{2}$, then $\delta = \frac{l2}{\pi} \frac{1}{\Delta}$, or, with sufficient accuracy, $\delta = \frac{.22}{\Delta}$.

Substituting the value of δ in the equation for V, we have $V = 2^{\frac{-X^2}{\Delta^2}}$. The value of Δ in the hydrogen curve is 19. Accordingly, after reducing to the same units as above, we have $\delta = 0.049$.

From these data fig. 3 *a*, Plate XLIII, was constructed, the full curve showing the distribution of light in the source.

Fig. 4 *b*, Plate XLIII, gives, in the full curve, the corrected values of the visibility of the blue hydrogen-line, at the same temperature and pressure as before. The dotted curve represents a double exponential, as before. The formula for this curve is

$$V = 2^{-X^2/24^2} \cos .7/28,$$

thus giving $\alpha = 0.08$ for the distance between the components, and $\delta = 0.057$ for the "half width" of each. These values give for the distribution of light in the blue hydrogen-line, the ful- curve in fig. 4 *a*.

Oxygen.

Fig. 5, Plate XLIII, represents the results obtained from oxygen prepared by heating a tube containing mercuric oxide, drying the gas by sulphuric acid, and exhausting and filling repeatedly till the spectrum was nearly pure. The lines are much less bright than those of hydrogen; and in order to obtain satisfactory results, the current had to be increased so far that the tube was frequently broken. Notwithstanding the somewhat uncertain character of the observations, it will be seen from fig. 5*a* that the curve for the orange-red line corresponds very well with that given by the formula

$$V = 2^{-X^2/34^2}[.36 + .32 \cos 2\pi X/2.69 + .16 \cos 2\pi X/4.85 + .16 \cos 2\pi X/1.73]^{\frac{1}{2}}.$$

The agreement between the coefficient $2^{-X^2/34^2}$ and the general curve drawn through the maxima is also shown in fig. 5 *b*, Plate XLIII.

The interpretation of these results is that the orange-red oxygen line is a triple, whose components have intensities in the ratios 1 : 1 : 1/2, and whose distances apart are 1.51 and 0.84 respectively, and whose "half-width" is 0.027. This is shown in fig. 5 *c*.

Sodium.

The results obtained from metallic sodium in the vacuum-tube are so varied, the character of the lines being so considerably altered by temperature and pressure, that a complete study is at present impossible. This is especially true of the yellow lines; and the difficulty is considerably increased on account of the insufficiency of the dispersion used, which does not permit the separate examination of the lines. Some reference to the changes mentioned will be given at the close of this paper. At present it will suffice to take a particular case—the pressure being very low, and the temperature about 250°.*

The full curve in fig. 6 *b*, Plate XLIII, gives the experimental result for the visibility at the maxima for yellow sodium, corrected for the personal equation. The dotted curve corresponds to the formula

$$V = 2^{-X^2/156^2} \cos .7/50 \cos .1/140.$$

The complete equation, assuming that the two lines are alike is,

$$V = 2^{-X^2/156^2} \cos .8/0.58 \cos .7/50 \cos .1/140.$$

The interpretation of these results is that each of the sodium-lines is a close double, as shown in fig. 6 *a*.

The yellow-green sodium-line at $\lambda = 5687$ is a double whose components are about the same distance apart as the yellow pair. It was found to be far less variable than the yellow; and the full visibility-curve, neglecting slight irregularities, gives the experimental results corrected for personal equation. Fig. 7 *b*, Plate XLIII, shows that its components are single, and correspond in distribution of light fairly well with the exponential curve, fig. 7 *a*.

The same may be said of the orange-red double at 6156 also, except that this seems to have a companion of feeble intensity.

The doubles at 5150 and at 4982 were also examined, the curves showing nearly the same results as the red.

Zinc.

The temperature at which the radiations from metallic zinc could be conveniently observed was in the neighborhood of the melting-point of the glass of which the vacuum-tubes were made. But few observations were recorded, though these were quite consistent. The results of the observations, corrected for personal equation, are given in figs. 8 and 9, Plate XLIII. The

* The curve given above was obtained a year ago; and since then it has been impossible to reproduce it exactly.

former is the record obtained from the red line near 6360, and shows that this line is single, the distribution of light agreeing very well with a simple exponential curve, the "half-width" being 0.013. The latter shows the results of observation on the blue line near 4811. The dotted curve is the visibility-curve due to a distribution represented in fig. 9 *a*.

Cadmium.

Metallic cadmium in the vacuum-tube at a temperature of about 280° gives a number of very bright lines, widely separated, and varying very slightly with temperature or pressure. Fig. 10 *b*, Plate XLIV, shows the experimental visibility-curve of the red line near 6439, corrected for the personal equation, together with the simple exponential curve $V = 2^{-X^2/138^2}$. The remarkably close agreement leaves no doubt that the distribution of light in the source follows very nearly the exponential law giving the curve in fig. 10 *a*, in which the "half-width" of the source is 0.0065.

The result of a single set of observations on the green line at 5086 is given in fig. 11 *b*, Plate XLIV, the approximate agreement between the full line and the dotted curve (which corresponds to the equation $V = 2^{-X^2/120^2} \cos .2/115$) showing that the source is a close double, the intensity of whose components is in the ratio 5 : 1, and whose distance apart is .022, the "half-width" of each component being 0.0048.

The curve for the blue radiation at 4800 is given in fig. 12 *b*, Plate XLIV, and shows that the results may be approximately represented by $V = 2^{-X^2/64^2} \cos .1/32$, which corresponds to the distribution of intensity given in fig. 12 *a*.

Thallium.

The metal is not sufficiently volatile at the temperatures attainable, but the chloride answers admirably, giving a brilliant green light, the visibility-curve varying but little with temperature. This curve is given in fig. 13 *b*, Plate XLIV., together with the dotted curve representing the equation

$$V = \tfrac{1}{8} \cos .2/160 \sqrt{4V_1^2 + V_2^2 + 4V_1V_2 \cos 2\pi X/25.3},$$

in which $V_1 = 2^{-X^2/246^2}$ and $V_2 = 2^{-X^2/188^2}$.

This is the visibility-curve due to a double source, each of whose components is a close double, as shown in fig. 13 *a*.

Mercury.

Mercury in a vacuum-tube gives two yellow lines 5790 and 5770, a very brilliant green line at 5461, and a violet line at 4358.

The yellow lines are not very bright, and are so close together that it is somewhat difficult with the dispersion employed to prevent the light from overlapping. Notwithstanding these difficulties, the close agreement of a number of observations shows that the curve for the lower line, given in fig. 14 *b*, Plate XLIV., is a close approximation to the truth. Neglecting the effect of a line of feeble intensity at a distance of about .24 from the principal line, the distribution of light in the source is represented in fig. 14 *a*, which gives for the visibility curve

$$V = \tfrac{1}{4}\sqrt{3V_1^2 + V_2^2 + 6V_1V_2 \cos 2\pi X/28},$$

in which $V_1 = 2^{-X^2/200^2}$ and $V_2 = 2^{-X^2/260^2}\cos .5/280$.

Fig. 15 *b*, Plate XLIV, represents the results of observations on the upper yellow line, omitting some peculiarities due to the presence of one or more lines of feeble intensity. The curve agrees closely with the formula

$$V = \tfrac{1}{4}\sqrt{3V_1^2 + V_2^2 + 6V_1V_2 \cos 2\pi X/70},$$

in which $V_1 = 2^{-X^2/183^2}$ and $V_2 = 2^{-X^2/126^2}$, which represents the visibility-curve produced by two lines of intensities 1 : 3 and separated by 0.019 divisions as shown in fig. 15 *a*.

The green mercury-line is one of the most complex yet examined. The constituent lines are nevertheless so fine that the interference-bands are frequently visible when the difference of path is over four-tenths of a metre. The full curve in fig. 16 *b*, Plate XLIV, gives the results of observations corrected for personal equation, while the dotted curve represents the equation

$$V = 2^{-X^2/230^2}\sqrt{.69V_1^2 + .03V_2^2 + .28V_1V_2 \cos 2\pi X/31.4},$$

in which $V_1 = .62 + .38 \cos 2\pi X/360$

and $V_2 = .77 + .23 \cos 2\pi X/110$.

This is the visibility-curve corresponding to the distribution represented in fig. 16 *a*. The components of the line, for simplicity, have been assumed to be symmetrical, as figured; but the observations are not sufficiently accurate to determine whether, for instance, each component is a double or a triple line. In this case also, as in the preceding ones, it is impossible from the data

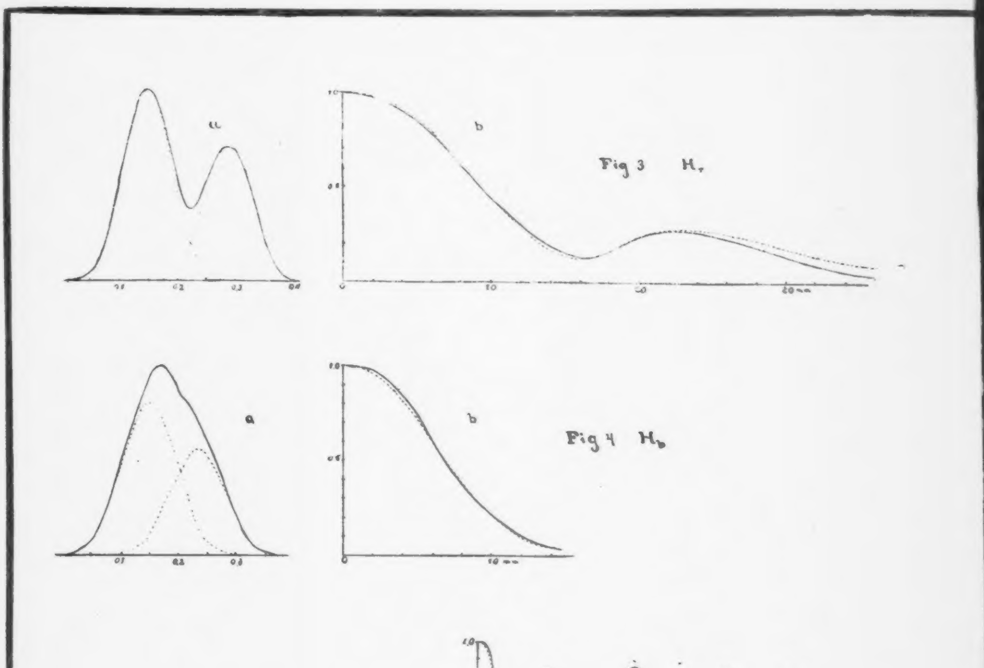
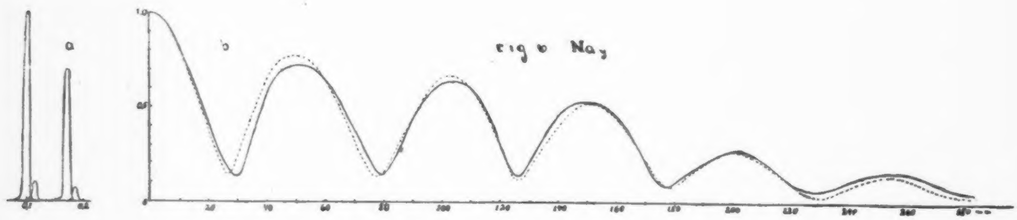
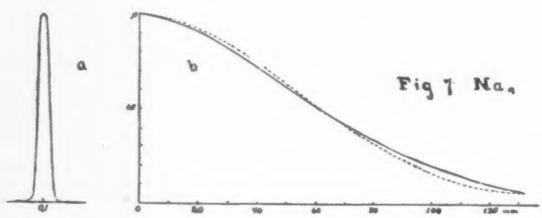
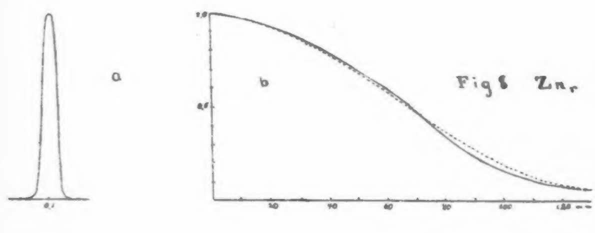
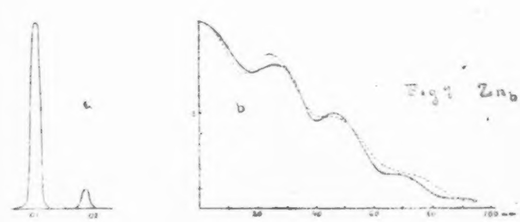

a
b
Fig 3
a
b
Fig 4
c
a
Fig 5
b

PLATE XLIII.









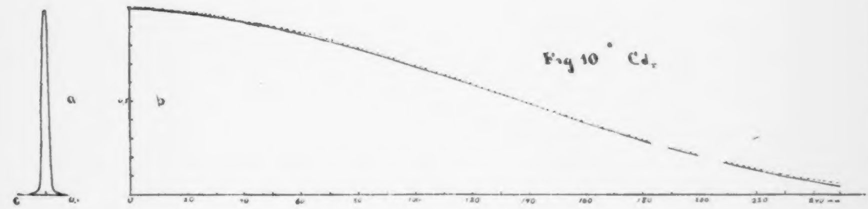


Fig 10 Cd

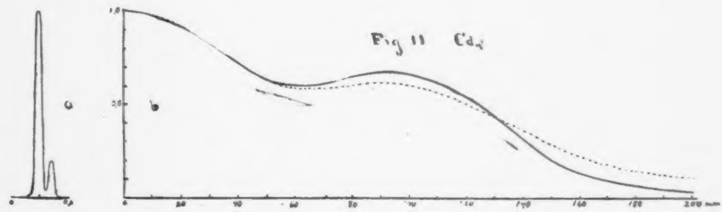


Fig 11 Cd

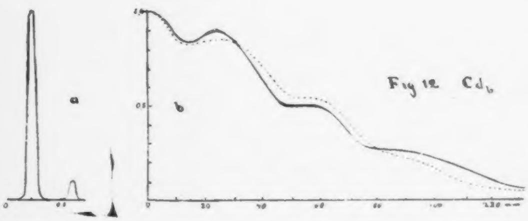
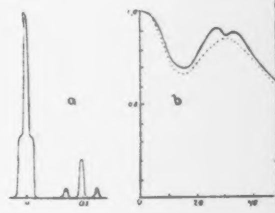


Fig 12 Cd



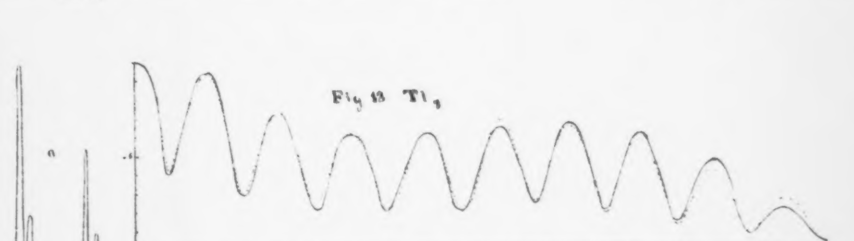
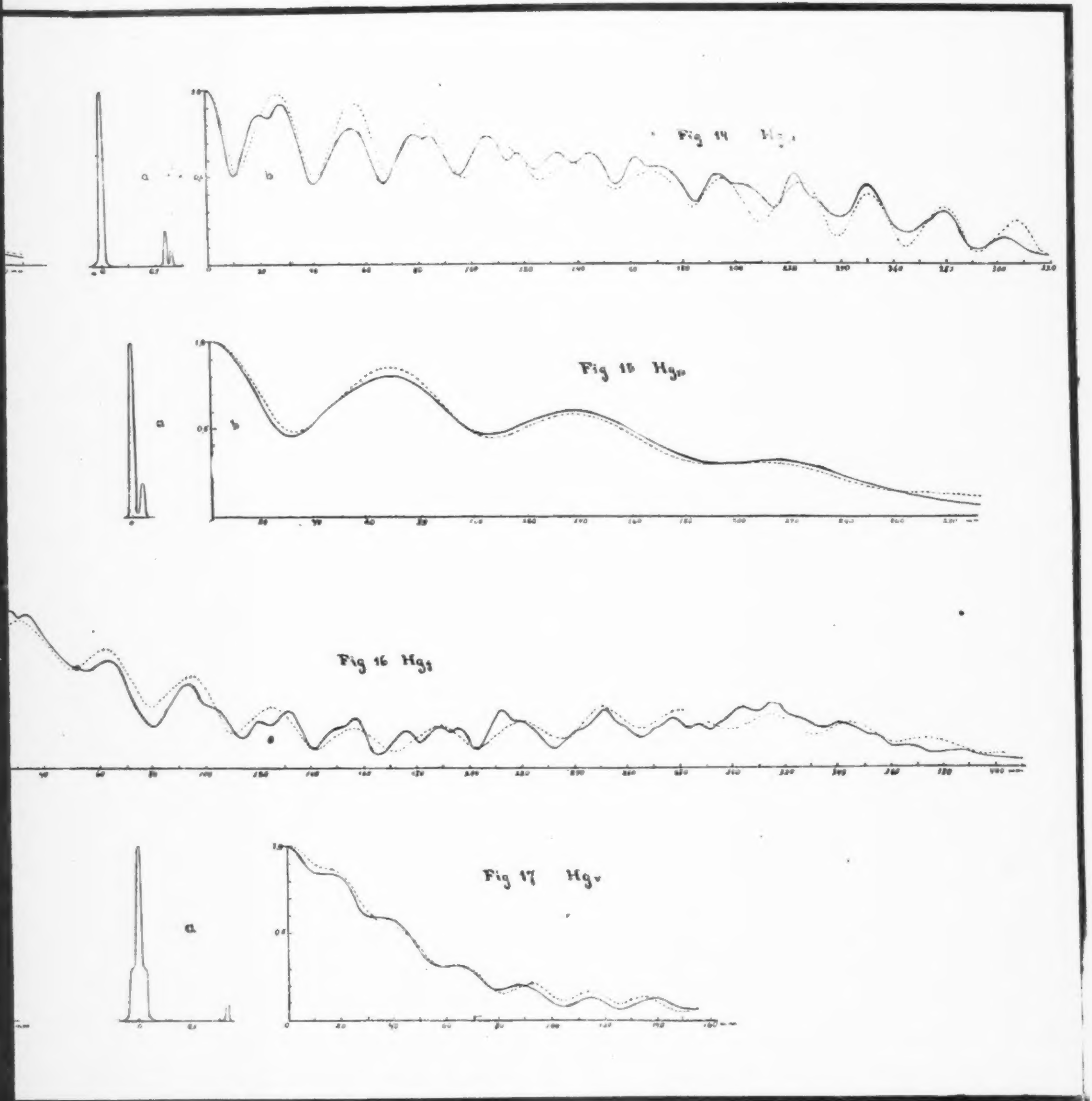


Fig 13 Tl

PLATE XLIV.



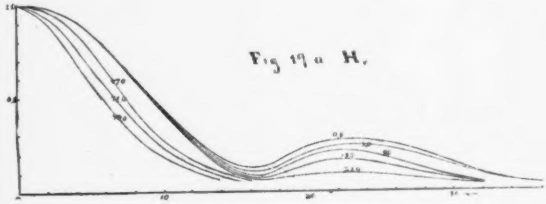


Fig 19 a H.

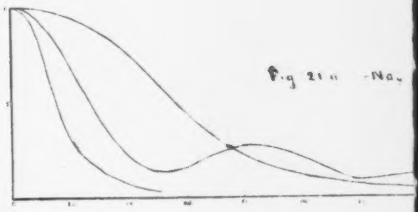


Fig 21 a Na.

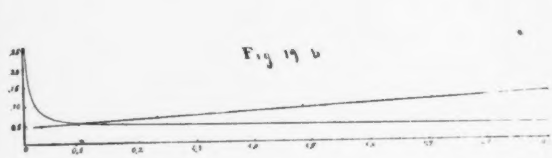


Fig 19 b

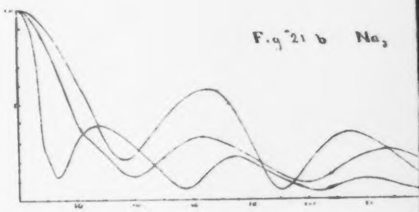


Fig 21 b Na.

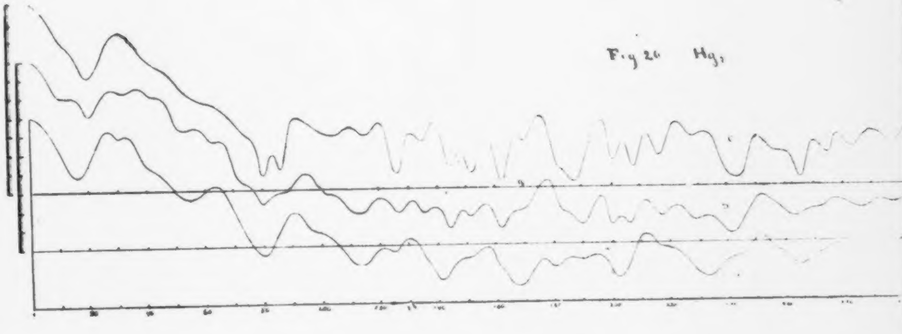


Fig 26 Hg.

Fig 21 a Na

Fig 22

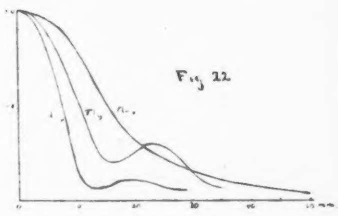
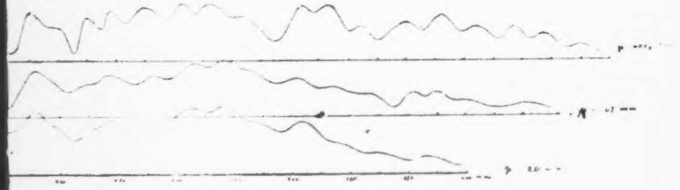
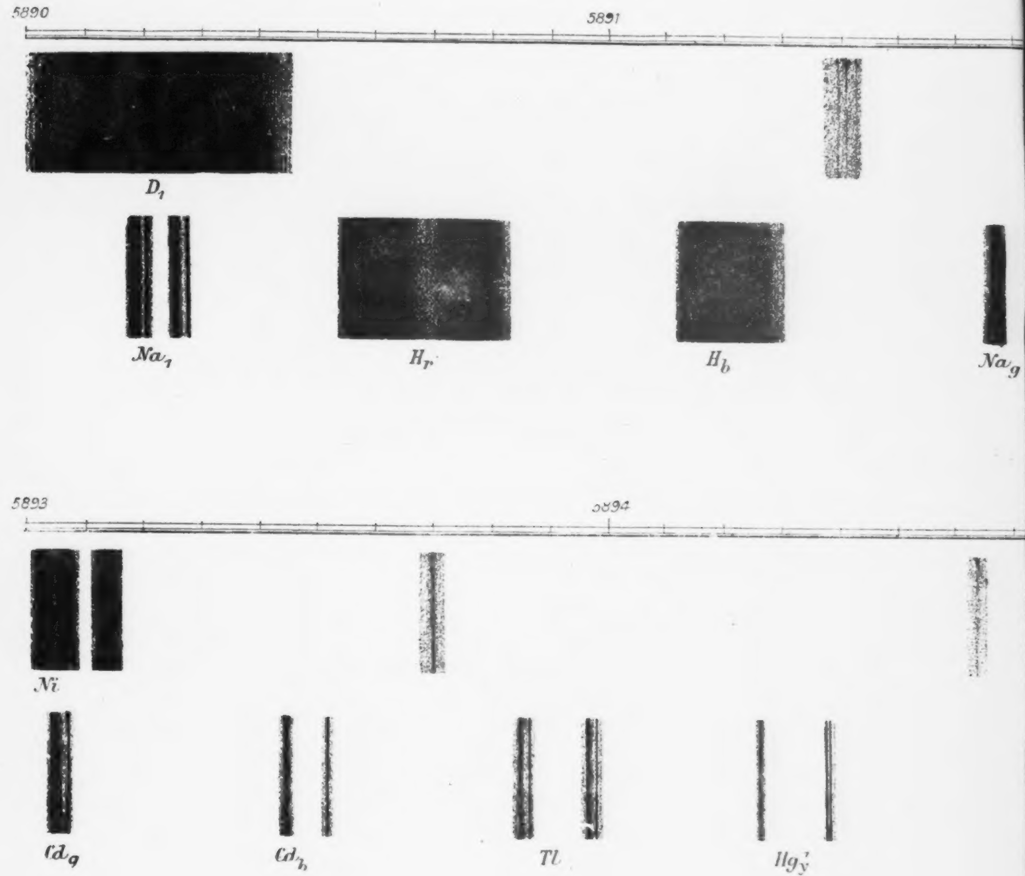
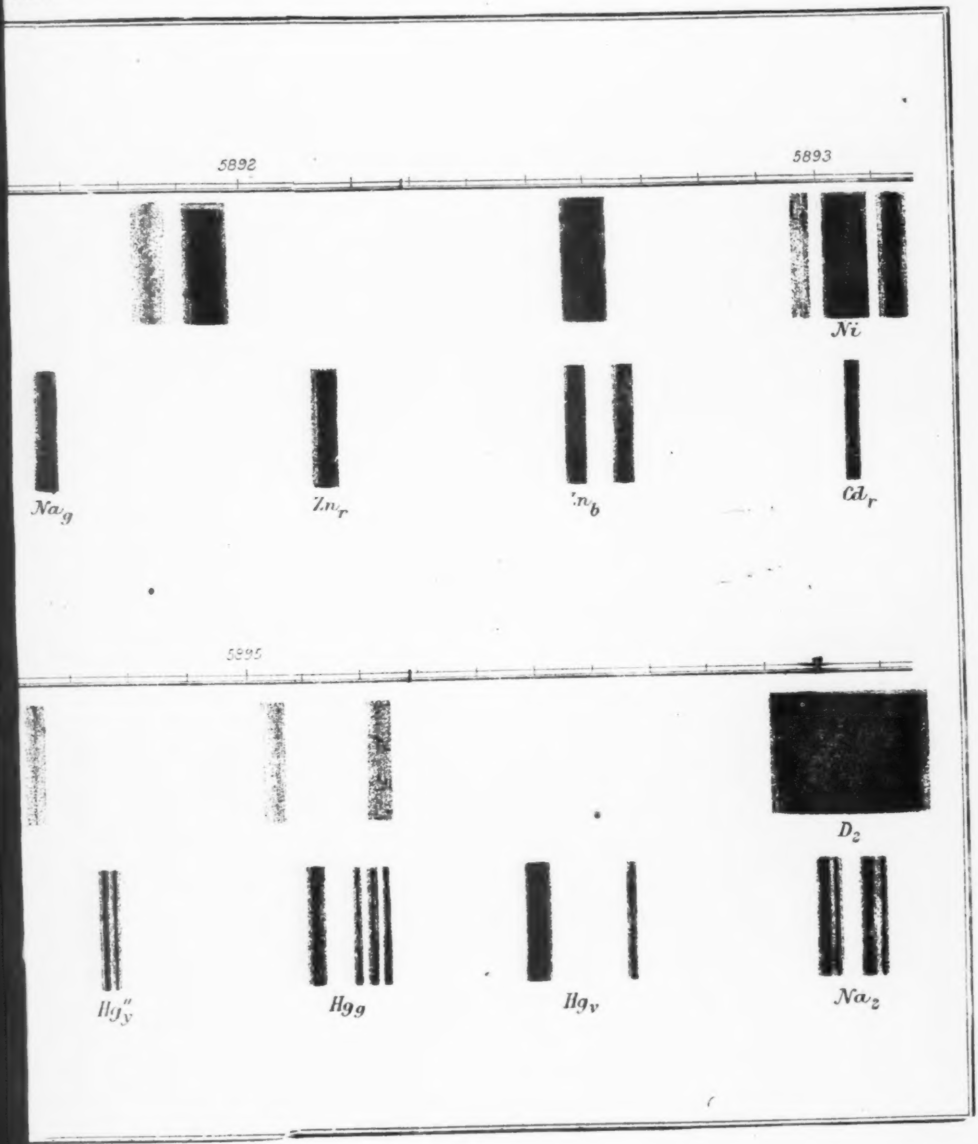


Fig 21 b Na




5890
5891
D_1
Na_1
H_r
H_b
Na_g
5893
5894
Ni
Cd_q
Cd_h
Tl
Hg'_y


5892
5893
Ni
Na_g
Zn_r
Cd_r
5895
D_2
Hg''_y
Hg_g
Hg_v
Na_2

given to determine whether the smaller component is to the right or left of the principal line. A direct observation with the grating showed, however, that the smaller component is towards the red end of the spectrum.

The full curve shows that there is at least one other line—probably more than one—whose intensity is roughly one twentieth of the principal line, and whose distance from it is about three times that of the chief components.

The violet mercury-line is much more difficult to observe than the others. The results obtained by observation, corrected for personal equations, are given by the full curve fig. 17 *b*, Plate XLIV. The formula for the dotted curve is

$$V = \sqrt{.88V_1^2 + .12V_1V_2 \cos 2\pi\, X/23},$$

in which $$V_1 = 2^{-X^2/74^2}[.62 + .38 \cos 2\pi\, X/200]$$

and $$V_2 = 2^{-X^2/120^2},$$

the resulting distribution of light shown in fig. 17 *a*.

The results of the preceding work are collected for comparison in fig. 18, Plate XLVI., together with the D group in the solar spectrum. From these, as well as from the curves, it will be seen that it is easy by this method to separate lines whose distance apart is only a thousandth of that between D_1 and D_2, and even to determine the distribution of light in the separate components. The conditions most favorable to high values of the visibility are low density and low temperature, and these conditions were complied with as far as possible. Still, in many cases, the range of visibility due to slight variations of the conditions show that the behavior of each substance must be carefully studied under all possible circumstances of temperature, pressure, strength of current, size and shape of the electrodes, diameter of the vacuum tube, etc.

The effect of temperature and of pressure on the visibility may be readily accounted for on the kinetic theory. In fact, there is but little doubt that these are the chief if not the sole causes of the broadening of the spectral lines and the consequent diminution of visibility; the latter cause acting by altering the period of the source by frequent collisions, and the former, by the change in the wave-length of the light due to the motion of the source in the line of sight.

If, now, the density of the vapor is very low, the second cause

may be ignored, and it will be shown that in the case of hydrogen this is the case when the presure is one or two millimetres.

In most of the cases investigated the pressure was so low that the discharge passed with difficulty. Supposing, then, the effect of collisions to be insignificant, let it be proposed to find the effect due to the motion of the molecule in the line of sight. If v be the mean velocity of the molecule and V that of light, then the formula for the resulting visibility-curve, as given by Lord Rayleigh* is $h = (1 - a'')/(1 + a'')$.

If the definition of visibility as given above be taken, however, this becomes

$$V = a'' = \exp\left[-\pi\left(\frac{\pi X}{\lambda}\frac{v}{V}\right)^2\right].$$

If Δ be the difference of path at which the visibility is reduced to half its value at $X = 0$, then

$$\Delta = \frac{1}{\pi}\sqrt{\frac{l2}{\pi}} \cdot \frac{V}{v}\lambda,$$

or approximately,

$$\frac{\Delta}{\lambda} = .15\frac{V}{v}.$$

If we take for hydrogen $v = 2000$ metres per second, then $\frac{\Delta}{\lambda} = 22500$.

Again, if we ignore the difference in the temperature (about which there is considerable uncertainty), at which the other substances were examined, the velocities v would vary inversely as the square root of the atomic weight, and the number of waves in the difference of path at which the visibility is 0.5 is therefore $22500\sqrt{m}$.

Considering the difficulties and uncertainties of the problem, the following Table shows a remarkable agreement between the values actually found and the calculated results.†

* "On the Limit to Interference when Light is Radiated from Moving Molecules," Phil. Mag. April 1889.

† It should be stated that the value of Δ for the yellow sodium-line, if taken from the curve, would be much larger than that given. The latter was the mean of a number of observations taken within the past month. As has been stated before, this particular curve has not been obtained since last year. A few other substances, very difficult to examine, either because the lines are too feeble, or because the spectrum is so unstable, have given results not quite so consistent as the above, though all are of the same order of magnitude as that required by theory.

Substance.	At. Wt.	λ.	Δ.	$N=\frac{\Delta}{\lambda}$.	N. (Calc).
H_r	1	656	19.0	30000	22500
H_b	1	486	8.5	18000	22500
O	16	616	34.0	55000	80000
Na_r	23	616	66.0	107000	108000
Na_y	23	589	80.0	133000	108000
Na_{gy}	23	567	62.0	109000	108000
$Na_g{}'$	23	515	44.0	85000	108000
$Na_g{}''$	23	498	55.0	110000	108000
Zn_r	65.5	636	66.0	104000	182000
Zn_b	65.5	481	47.0	98000	182000
Cd_r	112.0	644	138.0	215000	238000
Cd_g	112.0	509	120.0	236000	238000
Cd_b	112.0	480	64.0	134000	238000
$Hg_y{}'$	200.0	579	230.0	400000	317000
$Hg_y{}''$	200.0	577	154.0	270000	317000
Hg_g	200.0	546	230.0	420000	317000
Hg_b	200.0	436	100.0	230000	317000
Tl	203.6	535	220.0	400000	322000

In order to show conclusively that the effect of density may be neglected in the foregoing observations, as well as to ascertain the law governing the broadening of spectral lines by pressure or density, a series of observations was made on the red hydrogen-line at varying pressures, with the results shown in fig. 19 *a*, Plate XLV.*

From these curves the following Table was calculated :—

Pressure in millim.	δ
90	.128
71	.116
47	.095
23	.071
13	.056
9	.053
3	.050
5	.048

In fig. 19 *b* the curved line gives the relation between δ and $\frac{1}{p}$, and shows clearly that when p is less than 5 millim. the effect of collisions has almost entirely ceased. If we take as variables δ and p, the results agree very closely with the straight line $\delta-\delta_0=kp$, in which $\delta_0=.047$ (the "half-width" of the line at zero pressure in the units adopted), $k=.00093$, and p is the pressure in millimetres.†

The same results were found for the blue hydrogen-line, though, as might be expected, these were not so consistent.

It thus appears that in the case of hydrogen—and probably in all other cases—the width of the spectral line diminishes towards

* The numbers against the curves denote pressure in millimetres.

† In the figure, the numbers representing values of the abscissæ for this line should be multiplied by 100.

a limit as the pressure diminishes, which depends upon the substance and its temperature; and that the excess of width over this limit is simply proportional to the pressure.

In general, it may be said that, under considerable ranges of temperature and pressure, the character of the visibility-curve remains the same; but it may be important to note that there are a number of exceptions to this rule, among which the green mercury-line and the yellow sodium-line may be especially mentioned.

Thus, fig. 20 *a*, Plate XLV, represents the visibility-curve usually observed for the green mercury-line, and fig. 20 *c* represents that obtained when the vacuum is so high that the discharge passes with difficulty, while fig. 20 *b* represents the intermediate stage. This last observation was obtained by placing the mercury in an atmosphere of hydrogen whose pressure could be measured by a McLeod gauge.

It might be objected that the presence of a foreign substance might of itself affect the distribution of light in the source, and therefore the form of the curve. In order to test this point, a series of observations of the red hydrogen-line was taken, while the tube contained liquid mercury, which was heated until the mercury-spectrum was at least ten times as bright as that of the hydrogen. The character of the visibility-curve was not perceptibly altered.

In the same series of experiments it was found that, provided the pressure of the hydrogen remained constant, the effect of a change in temperature from 75° to 140° had no appreciable effect on the result. In this connection it may be mentioned that the character of the curve for the green mercury line was not essentially altered when, in place of metallic mercury, the nitrate, iodide, or the chloride was substituted, the only important effect being a diminution in the visibility in the order named.

In the case of yellow sodium light, it has already been mentioned that the character of the curve is more variable than that of any other line thus far examined. This is illustrated by the curves in figs. 21 *a* and 21 *b*, Plate XLV. It has not been possible thus far to devote the attention which a systematic investigation demands. These changes are very puzzling to trace, but undoubtedly much of the difficulty is due to the fact that the dispersion employed was not sufficient to permit the separate examination of the components. Still, there can be no doubt that the width of the lines, their distances apart, and their relative intensities vary rapidly with changes in temperature and pressure.

In addition to the preceding investigations of visibility-curves for light emanating from a rare gas or vapor in a vacuum-tube, the curves for sodium, thallium, and lithium in the flame of a Bunsen-burner have been observed; and the results are given in fig. 22, Plate XLV. The thallium and lithium-lines are clearly double; the distance between the components of the former agreeing very well with the results obtained with the vacuum-tube.

These substances were brought into the flame in the ordinary way, and the results obtained were at least as good as when a finely divided solution was used according to the method of Gouy. It appears from these curves that the width of the line is about ten times as great as when the vacuum-tube is used. But if the temperature of the flame be taken at 1500° C. and that in the vacuum-tubes at 350° C., the lines should be only twice as broad in the former case as in the latter. It appears, then, that notwithstanding the small quantity of substance present (barely enough to color the flame), the real density must be comparable to that of the vapor of the substance boiling under atmospheric pressure.

The principal object of the foregoing work is to illustrate the advantages which may be expected from a study of the variations of clearness of interference-fringes with increase in difference of path. The fundamental principal by which the "structure" of a line or group of lines is determined by this method is not essentially different from that of spectrum-analysis by the grating, both depending, in fact, on interference phenomena; but in consequence of the almost complete freedom from errors arising from defects in optical or mechanical parts, the method has extraordinary advantages for this special work. A glance at fig. 18, Plate XLV., will give a fair idea of the "resolving-power" of the method as compared with that of the grating. In order that the comparison be quite fair, however, it would be necessary to take for a comparison-spectrum that of the substances here used, and under the same conditions. With the best instrumental appliances now in use, it is difficult to "resolve" lines as close together as the components of either of the yellow sodium-lines. It is evident, however, that by *Light-wave Analysis* (if I may venture so to call the foregoing method) a tenth of this distance is obviously within the limit; indeed, if the width of the lines themselves be less than their distance apart, there can be no limit.

SUPPLEMENT.

I. It has already been pointed out that in many cases it is difficult or impossible to decide between two or more distributions of lines which give very nearly the same visibility-curve; and when there are many lines in the source, the combinations of intensities and arrangement of these from which a type may be selected is enormously great. Indeed, even when the number of lines is greater than three, excepting perhaps the cases where the lines may be in pairs (as in the case of yellow sodium-light), the resulting visibility-curve becomes so complex that it is very difficult to analyse. Doubtless in many cases where the components are not too close, the grating will give the information necessary for the investigator to select the proper combination.

It may readily be shown that the formula

$$V^2 = \frac{C^2 + S^2}{P^2},$$

for the *visibility*-curve due to a distribution of light, $y = \varphi(x')$, is identical with that of the *intensity*-curve at the focus of a telescope provided with apertures which produce this distribution in the light passing through. Accordingly, if a telescope be provided with apertures adjustable in width, (or length) and distance apart, the diffraction image of a distant illuminated slit will give, at once, a representation of the whole visibility-curve; and by adjustment of intensities and distances any particular visibility-curve may be more or less accurately copied, thus furnishing a means of studying the relations between V and $\varphi(x)$, which, while giving perhaps only a rough approximation to the truth, may prove more convenient than analytical or graphical methods.

II. One of the purposes which led to these investigations was the search for a radiation of sufficient homogeneity to serve as an ultimate standard of length. It will appear from the curves of cadmium that there are three lines which may be used for this purpose. The red cadmium-line is almost ideally homogeneous, and will readily permit the estimation of a change of phase in the interference-fringes of one hundredth of a fringe in a total distance of 200 millimetres, or over 300,000 waves.

Both the green and the blue lines are fairly well adapted for the purpose, and will prove very valuable as checks. Each of these, however, has a small companion, and it is necessary to know the effect of this in altering the phase of the interference-bands.

If φ be the fraction of a wave by which the position of a mini-

mum is shifted on account of the presence of the companion, α the number of "periods" in the difference of path, and r the ratio of the intensities, then

$$\tan 2\pi\varphi = -\frac{r \sin 2\pi\alpha}{1 + r \cos 2\pi\alpha}.*$$

Thus, if $r = 1/4$, φ is a maximum when α is about $1/3$; and for this we have, approximately, $\varphi = -.04$.

This is the largest correction to be applied, and is negative if the brighter line has the greater wave-length. It is theoretically possible, by this means, to determine, in case of an unequal double, or a line unsymmetrically broadened, whether the brighter side is toward the blue or the red end of the spectrum.

III. It has been argued that, even if all practical difficulties in making large gratings could be removed, nothing further could be gained in resolution of groups of spectral lines, on account of the real width of the lines themselves, caused by the lack of homogeneity in the radiations which produce them. The results of the preceding investigations show that, while this is very far from being true with present gratings, such a limit undoubtedly exists. The accordance between the measured widths of eighteen lines shows, further, that this broadening of lines in a rare gas can be fully accounted for by the application of Döppler's principle to the motion of the vibrating atoms in the line of sight, and indeed furnishes what may be considered one of the most direct proofs of the kinetic theory of gases.

The form of the ultimate components of all the groups of lines thus far examined is found to agree fairly well with an exponential curve, $\varphi(x) = e^{-a^2x^2}$, which shows that the distribution of velocities cannot vary widely from that demanded by Maxwell's theory.

If the limit above mentioned were due solely to the motion of the molecule, and the radiating substance could be rendered luminous while its temperature was very low, it might be possible to observe interference-phenomena with difference of path of many metres. But it must be considered that, since every vibrating molecule is communicating its energy to the æther in the form of light-waves, its vibrations must diminish in amplitude; consequently the train of waves is no longer homogeneous even though the vibrations remain absolutely isochronous, and the result is a broadening of the line and limitation of the difference of path at which interference is visible.

* See Phil. Mag. April 1891, page 345. (The value of r is the reciprocal of that here used.)

ON THE NEW STAR IN THE CONSTELLATION AURIGA.*

H. SEELIGER.

The phenomena presented by the new star in Auriga were in the highest degree remarkable. Spectroscopic, as well as photometric observations, were much more numerous than in previous apparitions of this kind, and for this reason they have sufficed to show that a number of explanations which had been given of earlier new stars, with more or less plausibility, are in the present case untenable. On the other hand, it is very difficult to combine the details of all the published observations in a manner which is desirable for a satisfactory test of a definite hypothesis. It therefore seems to me appropriate to present a new attempt at explanation, in a hypothesis which appears to agree better than others with the principal results of observation, but the final test of which in all its details must be left to the future. Should difficulties be encountered in applying it to the present case, which I admit is possible, though scarcely probable, it nevertheless deserves a somewhat exhaustive discussion, since it deals with conditions which I believe to be entirely possible, and it is therefore a valid hypothesis for the appearance of certain new stars. I shall therefore, in more firmly establishing this hypothesis, confine myself to the conditions which are regarded by observers as proved by the results of their observations, an examination of the latter not coming within the scope of these lines. I may state that I gave the substance of the following remarks in a treatise published in March of the present year.†

The principal results of observation, which may be regarded as characteristic of the entire phenomenon, are the following:

(1.) According to Herr Lindemann,‡ the light curve of the Nova exhibited these peculiarities:

"From the 1st to the 3d of February the photometric curve rose rapidly to a brightness of $4^m.7$, then sank gradually until Feb. 13th, and more rapidly until Feb. 16th, when the brightness was $5^m.8$. On Feb. 18th it reached a second maximum of $5^m.14$, had then on Feb. 23 a second minimum, likewise of $5^m.8$, then a third maximum on March 2 again of $5^m.4$, then sank, at first

* Translated from A. N. 3118. The unit of length adopted by Prof. Seeliger—the German geographical mile—has been retained in the translation, as the numerical results of the mathematical treatment are of no special importance. 1 German mile = 4.61 English miles.—Tr.

† Neber allgemeine Probleme der Mechanik des Himmels, S. 28. München, 1892.

‡ A. N. 3094.

slowly until March 6th, then quickly, in a straight line, reaching the $9^m.3$ on March 22d. To this is to be added that the photographs taken at Harvard College show that the star began to be visible in the beginning of December, 1891, and had already reached a maximum of brightness on Dec. 20—22, which however did not quite equal the later one on Feb. 3d.

(2.) The spectrum of the new star was very remarkable. Herr Vogel says in regard to it, summing up the results obtained at Potsdam*: "The observations have led to the altogether interesting result, that the spectrum of the Nova consists of two superposed spectra, and that a number of lines, particularly those of hydrogen, which appear bright in one spectrum and dark in the other, have a strong relative displacement. This result can hardly be interpreted otherwise than as signifying the presence of two bodies having a very considerable motion in the line of sight. . . . . . . The two bodies were separating with a relative velocity which did not vary appreciably during the four weeks of observation (in February), and which was at least 120 (German) miles per second." To this should be added that a number of maxima of brightness appeared in the very broad bright lines, two of them being fairly distinct. *

To explain these facts it has been assumed that two bodies passed very close to each other, and that the changes which were thereby produced in their atmospheres caused the sudden outburst of light. As thus stated, the hypothesis is much too vague for detailed application. It is true that, following a suggestion by Klinkerfues, an attempt has been made to form a more definite conception of the phenomenon, by assuming the existence of a powerful tidal action between the two bodies; at places covered by the flood of the atmospheric tide there would be a darkening due to absorption, and at the places of the ebb the reduction in thickness of the atmospheric strata would cause an accession of brightness. To this the objection must be made that the static theory of the tides, which is used throughout, is quite incapable of giving a correct representation of the deformations which are doubtless produced by the close passage of the two bodies; for with very eccentric orbits (which it is necessary to assume on other grounds), the continually varying action would last for so short a time that one could scarcely expect to derive a trustworthy conclusion in regard to the actual circumstances from a consideration based on the forms which the bodies could assume

* Vierteljahrschrift der Astr. Gesellsch. Band 27, S. 141.
* A. N. 3079.

in equilibrium;—not taking into account the fact that such a consideration generally yields only approximate results, the accuracy of which it is impossible to estimate. In the case of Nova Aurigæ particularly, as will be shown farther on, the action of the two bodies on each other must be regarded as arising almost suddenly and then vanishing. It should further not be overlooked, that the atmosphere of an incandescent heavenly body must be regarded as the outer envelope of a series of denser strata, and that these also are distorted, although by a smaller amount. On this account it has generally been held that the distortion is accompanied by eruptions of gas from the interior of the body. This assumption contains truly nothing impossible, but without greater definiteness it is scarcely serviceable for purposes of discussion. At any rate, it would be necessary to make still further hypotheses to make this explanation hold when applied to special cases. Thus, in the case of Nova Aurigæ there would still remain unexplained, why one spectrum is in the main an absorption spectrum, the other a spectrum of incandescent gas. It is true that this difficulty could be obviated by means of special assumptions, but it is not very probable that our confidence in the validity of the hypothesis would be thereby increased.

In Nova Aurigæ still other facts present themselves, which do not speak in favor of the hypothesis. It is at least very surprising that just here we should meet with cosmical masses moving with velocities so enormous as to be almost unprecedented. The existence of such velocities must, therefore, be regarded as one of the facts to be explained. Formulæ are given farther below which up to a certain point allow the mechanical conditions of the close passage of two cosmical bodies to be followed mathematically. From these formulæ it follows that in Nova Aurigæ the two bodies could describe parabolas around each other, only in case their united masses were very much greater than 15,000 times the mass of the Sun. For a hyperbolic motion it is possible to arrive at materially smaller masses only by assuming that the observed great relative velocity of 120 miles per second has been produced in only a small degree by their attraction, and that it existed almost entirely in the beginning. We have, therefore, either to choose the assumption of extremely great masses, or renounce an explanation of the great relative velocity. Now neither assumption contains an actual impossibllity, but I do not believe that unequivocal testimony for the correctness of the hypothesis can be recognized in either of them. In my mind they make the hypothesis very much less plausible.

The formulæ already mentioned show, as will be explained more fully below, that the supposed action of the two bodies in the present case must have passed off very rapidly, perhaps that it could have been brought into play for but a few hours. The action must necessarily have taken place at the first outburst of the star, in the beginning of December, 1891. Why, therefore, the Nova should have reached a second, and, to all appearances, greater maximum several weeks later (in the beginning of February, 1892), and further, why the light curve should have sunk slowly until the beginning of March and then have fallen off rapidly, seems to me to be scarcely, if at all, explicable, on the ground of the hypothesis above mentioned. The difficulty will at any rate exist until it is expressly obviated in all its details.

The difficulties which have been above briefly touched upon, disappear entirely in the light of the following considerations. The results obtained by astronomical photography, particularly the work of Herr Max Wolf, have left no doubt that space is filled with more or less extensive aggregations of thinly scattered matter. The physical constitution of these cosmical clouds will obviously differ greatly, and we may leave this question open, without investigating it further. Now, that a heavenly body should become involved in such a cosmical cloud is in itself not improbable, and at any rate it is much more probable than the close approach of another compact body required by the hypothesis which has been considered above. But as soon as a body enters such a cosmical cloud, its surface will begin to be heated, no matter what the constitution of the sparsely distributed material may be. In consequence of the superficial heating, vaporized products will form around the body, which will in part become detached from it and quickly assume the velocity of the neighboring parts of the cloud.

It will be appropriate to compare such an occurrence with the well known and quite similar one of shooting-stars or meteors. In this case, also, a compact body, moving with a certain velocity, penetrates a mass of very tenuous matter (the upper strata of the atmosphere); it is heated and partially vaporized, and its path is marked by a luminous train, which is often visible for a long time after the sudden appearance of the meteor. The separated particles quickly lose their velocity relatively to the air, for they scarcely seem to follow the motion of the meteor.

If the star thus made incandescent by resistance should be examined with a spectroscope, two superposed spectra would obviously be seen. One would in general be continuous, with ab-

sorbtion lines due to the glowing gaseous envelope; the other would consist principally of bright lines. Both spectra would be displaced with respect to each other by an amount depending upon the relative velocity in the line of sight. Thus the whole appearance would be quite similar to that observed in Nova Aurigæ, and a complete agreement may be brought about by assuming, if necessary, that physical changes due to direct heating effect, friction of the separated particles, etc., would take place in the parts of the cloud next to the solid body. In view of our ignorance of the properties of the cloud material, this assumption does not seem to me to offer any difficulties. Whether it is in any case necessary I do not need to decide for the purposes of the present article.

Of very great importance, however, is the investigation of the question whether we can in this way arrive at a plausible explanation of the great relative velocity indicated by the two spectra. On the approach of the body, the cloud would evidently be lengthened in the direction of approach. This lengthening and likewise the relative velocity of the individual cloud-particles with respect to the body, would grow with the increasing proximity of the latter. Without some definite provision in regard to the structure of the cloud, it is difficult to give any detailed representation of the phenomenon that will ensue, and we must content ourselves with considering some special case which will allow of closer investigation. If we assume, for example, that the separate particles of the cloud are in general influenced only by the attraction of the body, they will describe hyperbolas around the latter with its center as focus. Their greatest relative velocity will diminish rapidly with the distance from the body, so that the neighborhood of the latter will be filled with particles having very different velocities. It is easy to see that no extravagant assumption is required to obtain very great velocities for the particles which pass close to the surface of the body,—velocities such as have been proved to exist in the case of Nova Aurigæ, and this even when the initial velocity of the particles is very small. It also follows, from what has been shown above, that the spectral lines of particles moving away from the body with such different velocities must be greatly widened; moreover, not only is not the slightest difficulty encountered in explaining the different brightness of various parts of these lines, but the existence of such maxima of brightness follows as a necessary consequence. This point does not seem to me to be unimportant, since it cannot be deduced from the hypothesis of the close passage of

two compact masses, but leads to the very improbable assumption that there are several moving bodies of this kind.

As long as the body moves within the cosmical cloud, the appearances just described will be continually reproduced, and it follows that the characteristic features of the spectrum, apart from minor changes determined by all the circumstances of the case, must as a whole remain unchanged for a considerable time; a point which is not clear without further explanation on the ground of the first described hypothesis. It is also not surprising that during this time the brightness of the star should undergo little variation, but that it should fall off pretty rapidly after the emergence of the body from the cloud. This also agrees well with the observed light curve of the Nova. Finally, the periodic fluctuations of brightness are quite naturally explained. It is only necessary to remember the known fact, recently confirmed photographically by Herr Max Wolf, that the same phenomena are exhibited by meteors, and are explicable without difficulty.

We must in any case assume that the star entered the cosmical cloud in the beginning of December, and left it not long before the beginning of March. The question at once presents itself, how such a great relative velocity could exist for so long a time, notwithstanding a resitance sufficiently great to generate the heat required for the continuous incandescence of the body. We will decide this question by comparing the resisted motion of the star with that of a meteor in the upper layers of the atmosphere.

We may assume, with sufficient generality, that the rectilinear motion of the star is given by the equation

$$\frac{dv}{dt} = -\lambda v^n \tag{1}$$

in which v is the velocity, n is a positive number > 1, and λ is a constant which is proportional to the surface of the spherical body and the density of the medium, and inversely proportional to the mass of the body. Let us now compare equation (1) with the equation for the motion of a meteor,

$$\frac{dv'}{dt'} = -\lambda' v'^n$$

in which the time t' is now reckoned by another suitably chosen unit. If we place

$$v' = \mu v; \quad t' = \nu t; \quad \lambda = \lambda' \nu \mu^{n-1}, \tag{2}$$

the latter equation will be identical with (1); *i. e.*, the motion of the star will correspond at every point with the motion of the

meteor if equation (2) is satisfied. If we now represent by m, O, r, δ, respectively the mass, surface, radius, and density of the star, by m', O', r', δ', the corresponding quantities for the meteor, and by D and D' respectively the densities of the cosmical cloud and atmospheric layer in question, we have

$$\frac{\lambda}{\lambda'} = \frac{DOm'}{D'O'm}; \quad \nu = \frac{1}{\mu^{n-1}} \cdot \frac{DOm'}{D'O'm}$$

or also

$$\nu = \frac{t'}{t} = \left(\frac{\mathrm{v}}{\mathrm{v}'}\right)^{n-1} \cdot \frac{r'\delta' D}{r\delta D'} \qquad (3)$$

If we further place $r = k$ times the Sun's radius ($=700$ million metres) and $r' = r'$ metres, and in accordance with the observations of the new star, place $\mathrm{v} = 30$, (the unit being the Earth's orbital velocity), $t = 100$ days, and $\mathrm{v}' = 2$ (which corresponds to the velocity of a rather quickly moving meteor), and finally $n = 2$, then

$$\nu = \frac{15}{k} \cdot \frac{D\delta'}{D'\delta} \cdot \frac{r'}{700 \text{ mill.}}$$

and

$$t' = 0^{s}.185 f; \quad f = \frac{r'\delta' D}{k\delta D'}$$

The motion of the star falls off in 100 days by the same relative amount as that of the meteor in 0.185 seconds, if we place $f = 1$. Since we are, moreover, free to assume that $\frac{D}{D'}$ is small, we can reduce the time to a very small part of a second, and as in a few hundredths of a second the motion in the highest regions of the atmosphere is not sensibly retarded, there will likewise be no sensible retardation in the motion of the star. We have evidently a parallel to this result in the fact that the motion of a small body is more affected by atmospheric resistance than that of a large one, and that the resistance of the air has a much smaller effect on the orbital relations of large meteors than on those of small ones.

But we must now show that in spite of this small retardation of the motion of the body, sufficient kinetic energy is transformed into heat to cause the *superficial* incandescence of the star, such a state of incandescence, at least, having occurred in the case of Nova Aurigæ. We must therefore compute the quantities of heat Q and Q' which are generated per second on a unit surface of the two bodies respectively. If we call P and P' the loss of kinetic energy during the times t and t', and v_0 and v_0' the velocities before entering the resisting medium, then

$$Q = \frac{P}{Ot}; \quad Q' = \frac{P'}{O't'}$$

and

$$P = m(v_0^2 - v^2); \quad P' = m'(v_0'^2 - v'^2)$$

and with the aid of the previously deduced formulæ,

$$\frac{Q}{Q'} = \frac{D}{D'}\left(\frac{v}{v'}\right)^{n+1}$$

with the same numerical values as before, $\frac{v}{v'} = 15$; $n = 2$,

$$\frac{Q}{Q'} = 3375\,\frac{D}{D'}$$

so that we can assume that the density of the cosmical medium is very small compared with that of the extremely tenuous air in which the meteor is brought to incandescence, and still obtain the necessary quantity of heat. It is worthy of remark that all the numerical values can be varied within very wide limits without danger of contradiction. We therefore conclude that from this point of view also, no difficulties are opposed to the hypothesis which has been advanced.

I have now to deduce formulæ, which have been already referred to, and which are in themselves of considerable interest.

If we represent by μ the sum of the masses of two bodies moving around each other in conic sections, by V the velocity, and in other respects follow the customary notation, we have for the parabola,

$$V^2 = k^2\mu\frac{2}{r}; \quad r = \frac{q}{\cos^2\frac{1}{2}v}$$

$$\tan\tfrac{1}{2}v + \tfrac{1}{3}\tan^3\tfrac{1}{2}v = \frac{k\sqrt{\mu}t}{q^{\frac{3}{2}}\sqrt{2}}$$

from which immediately follows:

$$\mu = \frac{V^3 t}{4k^2 \sin\frac{1}{2}v[1 - \frac{2}{3}\sin^2\frac{1}{2}v]}.$$

Let us call c the velocity of the Earth in its orbit with radius R, and place the mass of the Sun plus that of the Earth $= 1$, so that $k^2 = c^2R$. If we further consider that the expression

$$\sin\tfrac{1}{2}v\,[1 - \tfrac{2}{3}\sin^2\tfrac{1}{2}v]$$

can attain the maximum value $\frac{\sqrt{2}}{3}$, it follows that

$$\mu > \frac{3}{4\sqrt{2}}\left(\frac{V}{c}\right)^3 \cdot \frac{ct}{R}$$

or if c is expressed in days,

$$\mu > 0.009123 \left(\frac{V}{c}\right)^3 t \qquad (4).$$

In order to apply this to the Nova, we must note that $\frac{V}{c} > 15$, since the orbital velocity can be considerably greater than the velocity in the line of sight. Further, more than two months elapsed after the supposed passage of the two bodies, which must nearly coincide with the time of periastron, up to the time at which spectroscopic observations could still be made. t is therefore much greater than 60. The formula (4)

$$\mu > 14779 \text{ times the mass of the Sun}$$

gives therefore a limit in which the masses are far too small. In reality we can perhaps takedouble this value without danger of contradiction.

Similar, although less simple considerations apply to the case of hyperbolic motion.

If V_0 represents the velocity at an infinite distance, we have

$$V^2 - V_0^2 = \frac{2k^2\mu}{r}$$

and according to the Theoria Motus,

$$\frac{r}{a} = \frac{e - \cos F}{\cos F};$$

$$e \tan F - \log \tan (45^\circ + \tfrac{1}{2}F) = \frac{k\sqrt{\mu}t}{a^{\frac{3}{2}}},$$

from which we find at once,

$$\left.\begin{aligned} \mu &= \left(1 - \frac{V_0^2}{V^2}\right)^{\frac{3}{2}} \cdot \left(\frac{V}{c\sqrt{2}}\right)^3 \cdot \frac{cA}{R}\, X \\ X &= \left(\frac{e - \cos F}{\cos F}\right)^{\frac{3}{2}} \cdot \frac{1}{e \tan F - \log \tan (45^\circ + \frac{1}{2}F)} \end{aligned}\right\} (5).$$

As F increases from 0° to 90°, the expression for X first diminishes, reaches a minimum, and then increases up to infinity. The minimum value is readily determined from the condition

$$\frac{3}{4} \; \frac{e \sin 2F}{(e - \cos F)^2} \left[e \tan F - \log \tan (45^\circ + \tfrac{1}{2}F)\right] = 1.$$

This equation is easily solved for special values of e. For the purposes of the present investigation I have adopted another course, assigning various special values to e and computing the corresponding values of X, as shown in the following table:

	e = 1.5	2.0	4.0	6.0	8.0	10.0
$F = 4°$	10.207	14.393	24.882	32.111	37.988	43.071
8	5.224	7.302	12.554	16.182	19.135	21.689
12	3.614	4.987	8.494	10.930	12.913	14.630
16	2.852	3.866	6.505	8.348	9.853	11.156
20	2.429	3.226	5.345	6.838	8.059	9.118
24	2.178	2.827	4.603	5.866	6.902	7.802
28	2.027	2.569	4.343	5.204	6.112	6.902
32	1.941	2.400	3.753	4.740	5.555	6.265
36	1.900	2.293	3.510	4.411	5.158	5.810
40	1.892	2.234	3.345	4.181	4.877	5.486
44	1.911	2.211	3.240	4.029	4.688	5.266
48	1.953	2.220	3.187	3.941	4.574	5.131
52	2.017	2.257	3.179	3.911	4.528	5.072
56	2.101	2.323	3.217	3.936	4.547	5.086
60	2.208	2.420	3.301	4.020	4.633	5.175
64	2.341	2.552	3.438	4.170	4.797	5.351
68	2.510	2.729	3.644	4.404	5.056	5.635
72	2.728	2.968	3.944	4.754	5.451	6.070
76	3.026	3.307	4.390	5.286	6.055	6.739
80	3.477	3.830	5.108	6.152	7.048	7.843
84	4.308	4.802	6.480	7.824	8.972	9.991
88	6.991	7.938	10.960	13.320	15.321	17.091

For very large values of e the minimum of X occurs when

$$\sin F = \sqrt{\frac{2}{3}}$$

and the minimum value is

$$\text{Min } X = \sqrt{\frac{3^{\frac{3}{2}} e}{2}} = 1.612 \sqrt{e}. \qquad (6)$$

We shall make no appreciable error if we use (6) for values of e not very different from unity, as will be seen in the following table, where the minimum values taken from the preceding table and those computed from formula (6) are placed side by side.

E	Direct.	Formula.
1	1.5	1.6
1.5	1.9	2.0
2	2.2	2.3
4	3.2	3.2
6	3.9	3.9
8	4.5	4.6
10	5.1	5.1

We thus obtain:

$$\mu > 0.0104\left(1 - \frac{V_0^2}{V^2}\right)^{\frac{3}{2}} \left(\frac{V}{c}\right)^3 \sqrt{e}\,.\,t. \qquad (7)$$

For the assumption $t = 60$, $\frac{V}{c} = 30$, we get

$$\mu > 16800 \sqrt{e}\left(1 - \frac{V_0^2}{V^2}\right)^{\frac{3}{2}}$$

a formula which holds for values of e not quite equal to 1. In order to include the parabola also we may write

$$\mu > 15000\sqrt{e}\left(\frac{V^2 - V_0^2}{V^2}\right)^{\frac{3}{2}} \qquad (7a)$$

Therefore in this case also we either arrive at masses which are extremely great, and therefore not very probable, or else we must assume that $\frac{V_0}{V}$ is very nearly $= 1$. Even for $\frac{V_0}{V} = 0.9$ we find from the above formula

$$\mu > 1200\sqrt{e},$$

from which it will be seen that the above assertion is justified. It has already been remarked that this inequality merely states that μ is very much greater than the right hand side. It is in fact easy, when $\frac{V_0}{V}$ does not differ much from unity, to find a superior limit for μ. If we place

$$\frac{V^2 - V_0^2}{V^2 + V_0^2} = \nu$$

we have

$$\cos F = \nu e$$

and by formula (5),

$$\mu = \left(\frac{1-\nu}{1+\nu}\right)^{\frac{3}{2}}\left(\frac{V}{c}\right)^3 \frac{ct}{R} \cdot \frac{\nu}{e\nu \tan F - \nu \log \tan (45^\circ + \frac{1}{2} F)}$$

For given values of t, e and ν we can compute the value of the right hand side. We will, however, seek the maximum value of $y = e\nu \tan F - \nu \log \tan(45^\circ + \frac{1}{2}F) = \sin F - \nu \log \tan(45^\circ + \frac{1}{2}F)$ by determining e as a function of ν.

$$\frac{dy}{de} = \left(\cos F - \frac{\nu}{\cos F}\right)\frac{dF}{de} = \frac{\nu(1 - \nu e^2)}{e\sqrt{1 - \nu^2 e^2}}$$

y therefore increases as long as $c < \frac{1}{\sqrt{\nu}}$ and diminishes continuously for $e > \frac{1}{\sqrt{V}}$. y is therefore a maximum when $e^2 = \frac{1}{\nu}$, and the maximum value is

$$y = \sqrt{1 - \nu} - \nu \log\left(\frac{1 + \sqrt{1 - \nu}}{\sqrt{\nu}}\right)$$

We have therefore

$$\mu > \frac{ct}{k}\left(\frac{V}{c}\right)^3\left(\frac{1-\nu}{1+\nu}\right)^{\frac{3}{2}} \cdot \frac{\nu}{\sqrt{1-\nu} - \nu \log\left(\frac{1+\sqrt{1-\nu}}{\sqrt{\nu}}\right)} \qquad (8)$$

and with $\frac{V}{c} = 30$, $t = 60$ days,

$$\mu > 27800\left(\frac{1-\nu}{1+\nu}\right)^{\frac{3}{2}} \cdot \frac{\nu}{\sqrt{1-\nu} - \nu \log\left(\frac{1+\sqrt{1-\nu}}{\sqrt{\nu}}\right)}$$

For the above example $\frac{V_0}{V} = 0.9$, the result is now

$$\mu > 2800$$

thus a considerably greater mass than before.

I have now to give a more complete proof of the statement that the two bodies could be in close proximity for a very short time only. For this purpose we make use of the following relations:

For the parabola we have found

$$\mu = \frac{V^3 t}{4k^2 x}; \quad x = \sin\tfrac{1}{2}v[1 - \tfrac{2}{3}\sin^2\tfrac{1}{2}v]$$

from which it follows, since $V^2 = \frac{2k^2\mu}{\nu}$, that

$$r = \frac{Vt}{2x}$$

We have therefore

$$r > \frac{3}{2\sqrt{2}} Vt = 1.06\,Vt. \tag{9}$$

For the hyperbola we have

$$r = \frac{2k^2\mu}{V^2 - V_0^2}$$

and by formula (5)

$$2k^2\mu = \frac{(V^2 - V_0^2)^{\frac{3}{2}}}{\sqrt{2}} tX,$$

therefore

$$r = \frac{\sqrt{V^2 - V_0^2}}{\sqrt{2}} tX$$

For excentricities which are not quite equal to unity we had

$$X > \frac{3^{\frac{3}{4}}}{\sqrt{2}} \sqrt{e}$$

hence in either case

$$r > \frac{3^{\frac{3}{4}}}{2} \sqrt{e} \, . \sqrt{V^2 - V_0^2}\; t > 1.06\sqrt{V^2 - V_0^2}\; t \tag{10}$$

For $V_0 = 0$, (10) of course becomes the same as (9). For the hyperbola we can apply a second relation.

Since
$$2\frac{a}{r} = \frac{V^2 - V_0^2}{V_0^2}$$
formula (5) may be written
$$k^2\mu = \left(\frac{a}{r}\right)^{\frac{3}{2}} V_0^{\,3} t X$$
and since $k^2\mu = aV_0^2$, it follows that
$$r = \sqrt{\frac{a}{r}} \,.\, V_0 t X = V_0 t y$$
in which
$$y = \frac{e - \cos F}{\cos F} \cdot \frac{1}{e \tan F - \log \tan (45° + \tfrac{1}{2} F)}$$
We now readily find that
$$\frac{dy}{dF} = \frac{-1}{e \sin F - \cos F \log \tan (45° + \frac{1}{2}F)} \cdot$$
$$[(1 + e^2) \cos F - 2e + e \sin F \log \tan (45° + \tfrac{1}{2}F)]$$
It is easy to see that the bracketed expression is always positive, since
$\log \tan (45° + \frac{1}{2}F) = 2 \tan \frac{1}{2}F + \frac{2}{3} \tan^3 \frac{1}{2}F + \ldots . > 2 \tan \frac{1}{2}F$
and consequently the expression in brackets $> (e - 1)^2 \cos F$.
$\frac{dy}{dF}$ is therefore negative, and y diminishes as F increases. From this it follows that
$$y > 1$$
and we obtain the relation
$$r > V_0 t. \qquad (11)$$

Applying this formula to the case of Nova Aurigæ we find that for

$\frac{V_0}{V}$	$\sqrt{V^2 - V_0^2}$	V_0
= 0.5;	= 108 miles;	= 60
0.6	96	72
0.7	86	84
0.8	72	96
0.9	—	108

Near perihelion the velocity was in all cases greater than 120 miles, and we shall therefore obtain values of r quite materially too small if we place
$$r > t \times 85 \text{ miles}.$$

For one day either before or after perihelion it is therefore certain that
$$r > 7.3 \text{ million miles}.$$

It can therefore hardly be assumed that any mutual action be-

teen the supposed two bodies which is worthy of consideration could have lasted for more than a couple of hours.

MUNICH, July, 1892.

POSTSCRIPT.

Since the above article was written, the reappearance of Nova Aurigæ, and particularly the observations of Mr. Barnard, have again awakened interest in this star. So far as the reappearance of the star is concerned, it will be seen that this must be regarded as a visible confirmation of such parts of my article as are devoted to criticism. The hypothesis which I have advanced is moreover in no way contradicted, for it is from the nature of the case very probable that the supposed nebulous clouds, or aggregations of dust-like particles, should be more numerous in certain parts of space than in others. It is also allowable to make a great variety of assumptions in regard to the distribution of the denser parts of these clouds.

In regard to the observations of Mr. Barnard I have to add the following remarks: I had formed a mental picture of the processes that caused the outburst of the Nova, which was so completely realized in Mr. Barnard's drawing that I could desire no more perfect representation of it. No appearance of the kind was seen, so far as I know, during the winter. This naturally does not imply that it did not exist, and it seemed to be possible that photography, as often before in similar cases, might have some information to furnish. I therefore, in May of the present year, inquired of Dr. M. Wolf at Heidelberg whether he had any long-exposure photographs of the vicinity of the Nova, taken at that time, and if so, whether a nebulous object could be found on them. Unfortunately Dr. Wolf had none. It is indeed doubtful, from Mr. Barnard's description, whether so small an object would have been visible on a photographic plate.

ON THE CONDITION OF THE SUN'S SURFACE IN JUNE AND JULY, 1892, AS COMPARED WITH THE RECORD OF TERRESTRIAL MAGNETISM.*

GEORGE E. HALE.

The large collection of solar photographs which has already accumulated at the Kenwood Observatory places at our disposal a nearly complete record of the condition of the Sun's surface from

* Communicated by the author.

the first of last February up to the present time. The greater part of them have been taken with the spectroheliograph, and are of special value in the study of faculæ. The remarkable disturbance photographed on July 15 has led to a preliminary examination of the plates giving the early history of the spot in which it occurred, in order to trace, if possible, some relation between the condition of the solar surface and the simultaneous record of terrestrial magnetism. I am indebted to Mr. S. J. Brown of the U. S. Naval Observatory for copies of the magnetic record for the period July 11—17. A description of the Stonyhurst curves for the period June 11—July 29 is given by the Rev. Walter Sidgreaves in his article in the November number of ASTRONOMY AND ASTRO-PHYSICS. The following notes refer only to some of the more important features of the photographs, the complete reduction of the plates having not yet been undertaken. For convenience of reference the plate-numbers recorded in the observatory note-book are used in the discussion.

The position on the Sun's surface of the spot group in which the disturbance of July 15 occurred is first indicated on plate 752 (June 10, 1^h 29^m)* by a small and faint facula near the eastern limb. On plate 764 (June 11, 11^h 25^m) the facula has advanced on to the disc, and is still very faint. On the same date a large group of bright faculæ in the northern hemisphere of the Sun has just reached the central meridian. Plates 767 to 773 show no material changes in the small facula. On plate 775 (June 13, 10^h 40^m) the facula is well advanced on the disc, and contains a small spot. It is still quite faint and inconspicuous. On the same plate there is a large group of bright faculæ in the southern hemisphere, and several groups of faculæ extending entirely across the disc in the northern hemisphere. One of these contains two spots of considerable size, and has but recently crossed the central meridian. Plate 776 was taken shortly after 775, and shows the facula around Spot A† to be fairly bright, though still inconspicuous. The brighter (northern) portion of the facula has a curved form, and terminates in a knob-like expansion at each end. Plate 777 was taken an hour later, and shows slight changes in the form. On plate 780 (June 14, 11^h 53^m) the facula has undergone a marked change, and considerably increased in length. A large group of faculæ is near the meridian at this time. On plate 784 (June 15, 10^h 27^m) the facula is larger and

* In all records given in this paper Chicago Mean Time is used unless otherwise stated

† For convenience of reference, the spot-group in which the disturbance of July 15 occurred will be called "Spot A".

brighter, and exactly on the central meridian. A large group in the northern hemisphere is also on the meridian. Plates 785, 786, 787, 789, 790 (the last taken June 15, $2^h\ 27^m$), record no important changes. On plate 791 (June 16, $10^h\ 47^m$) the form of the facula is very materially changed; no increase in brightness is noticeable, however. On the same plate there is a bright facula on the central meridian in the northern hemisphere. Plates 792, 793, 794 (the last taken June 16, $11^h\ 48^m$), show no changes. On plate 799 (June 17, $12^h\ 19^m$) the facula has become a brilliant, roughly circular object, preceding a single large spot, and containing two other smaller spots. On the following side of the large spot there is a narrow faculous border. The facula is totally unlike that shown on plate 794, which contains only faint traces of very small spots. A marked disturbance accompanying the formation of the spots therefore occurred between June 16, $11^h\ 48^m$ and June 17, $12^h\ 19^m$.

From Father Sidgreaves' paper we learn that "the magnets had been perfectly quiet from June 11 until at about 3 P. M. G. M. T. on the 16th, a slight disturbance commenced in the longitudinal force magnet. This continued, and later appeared in all three elements as a series of small intermittent oscillations, which lasted until the morning of the 18th." As Chicago is $5^h\ 50^m$ west of Greenwich, the disturbance of the magnets commenced June 16, $9^h\ 10^m$ Chicago M. T. Plate 794 was taken $2^h\ 38^m$ later, and up to this time no marked change had taken place in Spot A. On this plate there is a bright facula on the central meridian in the northern hemisphere, but there is nothing at the eastern limb of the Sun. Plate 799, which shows both prominences and faculæ in addition to spots, records no disturbance at the eastern limb, but shows a faint facula on the central meridian. It is evident, therefore, that so far as our records go, the magnetic perturbation was not caused by a simultaneous disturbance at the eastern limb of the Sun. As to whether it was caused by the sudden change in the spot, or, in accordance with Marchand's theory, by the passage of spots and faculæ across the central meridian of the Sun, we have no means of deciding. I am myself inclined to the former supposition, though it is of course quite possible that the magnetic perturbation was related to neither of these events.

We are informed by Father Sidgreaves that a series of small oscillations in the magnets again commenced on June 21, and continued until the morning of the 26th. An examination of the photographs does not seem to show any connection of Spot A with this disturbance. The spot and accompanying faculæ

passed quietly around the western limb, if we may judge from photographs taken just before and just after the passage. Plate 811 (June 20, 1^h 35^m) is an excellent composite photograph showing both faculæ and prominences. On this plate Spot A is a short distance from the western limb, where there is shown only a long, low prominence. On plate 815 (June 22, 9^h 39^m) Spot A has disappeared behind the limb, and in a composite plate (817) taken at 4^h 22^m on the same day, no prominence is shown at the point where the spot disappeared.

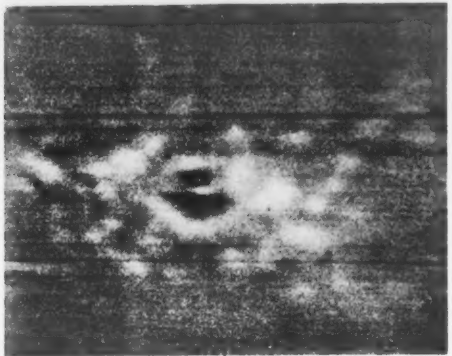
There were, however, two very active groups of faculæ and spots on the Sun at this time. One of these was a large spot group with faculæ in the southern hemisphere, which changed greatly between June 17, 2^h 43^m (plate 801) and June 20, 9^h 42^m (plate 802). During this time the large (preceding) nucleus divided into two, each equalling the original single nucleus in area, and the smaller (following) nucleus acted similarly, a new nucleus adding itself to it. Another small nucleus also appeared in the northern part of the group. The activity in this group continued, and on June 22, 9^h 39^m (plate 815) there were three large nuclei, with bright faculæ following.

But a more remarkable group was one in the northern hemisphere, which is shown on plate 802 (June 20, 9^h 42^m) near the eastern limb. It then consisted of a large group of faculæ, with two well marked spot nuclei in the southern part of the group. Plate 806 (June 20, 11^h 27^m) shows the facula of about the same form, except for a marked change in the northern part of the group, a change somewhat similar to the phenomenon of July 15, though on a much smaller scale. Between two bright points—one of which seems to correspond with a small spot nucleus, and the other with a bright point, shown on plate 804 (June 20, 10^h 11^m)—there extends a straight, bright object, no trace of which is shown on plate 804, taken 1^h 16^m earlier. The bright object lies across a portion of the facula, and does not seem to affect its form in the least. In plates 807 (11^h 34^m) and 808 (12^h 30^m) it has given place to a broad and ill-defined expansion, which is much fainter; but the bright point, shown also on plate 804, in which the outburst may have had its origin, still remains.

During the same time other minor changes took place in the group. Plates 809, 810, 811 show no marked changes. On plate 815 (June 22, 9^h 39^m) the group has advanced well on to the disc, and is greatly changed in form. It is greatly lengthened in an east and west direction, and two well defined spot nuclei have appeared preceding it, where before there was only a small, faint

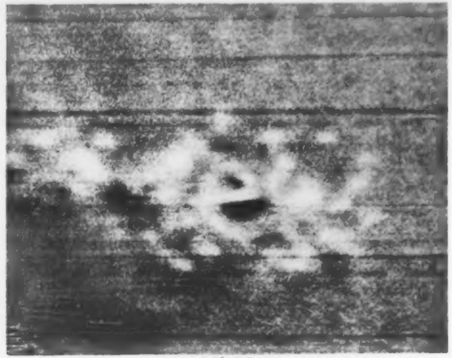
PLATE XLVI.

1



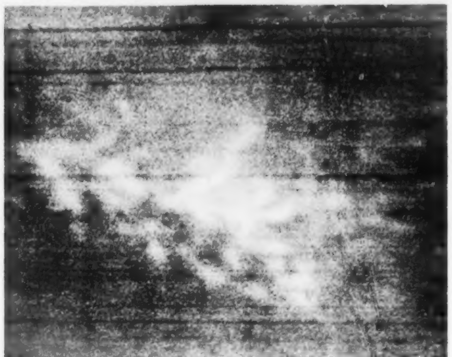
$11^h\ 8^m$

2



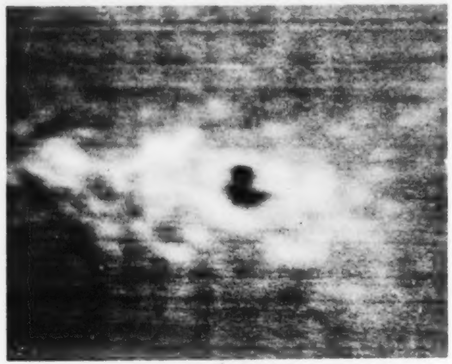
$11^h\ 20^m$

3



$11^h\ 47^m$

4



$2^h\ 0^m$

Solar Eruption Photographed July 15, 1892, with the Spectroheliograph of the Kenwood Observatory.

facula. This facula was long and narrow, convex toward the equator, and the spots formed exactly at its east and west extremities. In none of the preceding plates can any trace of these spots be seen, though the facula is well shown. Plate 819 (June 23, 1^h 53^m) shows the group on the central meridian; the four spots are arranged in a line nearly parallel to the equator, and marked changes have taken place in their relative distances. Nothing is shown at the eastern limb of the Sun. On Plate 821 (June 24, 2^h 27^m) considerable change is shown in the facula since plate 819. The following part of the group has reached the central meridian. Of the four spots the two middle ones, which were approaching when plate 819 was taken, are now nearly in contact. At the eastern limb there are two prominence disturbances in the northern hemisphere. Plate 822 shows that these eruptions had become much fainter twelve minutes later. Plate 824 (June 25, 11^h 37^m) shows no important changes in the facula, but the two middle spots are now in contact. There is a bright prominence at the eastern limb. Plates 825, 827, 828, 829, 830, 831 (the last taken June 25, 3^h 35^m) record nothing of present importance.

At this time the spectroheliograph was dismounted for several days while the new photographic objective was being attached to the telescope. The next photograph of faculæ (plate 838) was consequently not taken until July 5, at 12^h 6^m. At this time there were two large groups near the eastern limb, one in the northern and one in the southern hemisphere. There was also a group of faculæ in the northern hemisphere, which had just crossed the central meridian. Plates 839, 840, 842, 843, 844, 846 (the last taken July 6, 10^h 20^m), differ but little from plate 838. On plate 846 a prominence is shown at the point on the eastern limb where Spot A appeared later. The same prominence is shown on plates 847 and 849.

It is thus seen that the magnetic disturbance beginning on June 21, and continuing until June 26, was simultaneous with the passage of two active spot groups across the solar surface. No mention is made by Father Sidgreaves of a magnetic disturbance on June 20, at the time of the outburst which has been described as somewhat similar to the much more violent outburst of July 15. The oscillations of the magnets commenced one day later, on June 21, and this retardation together with the fact that the July 15 outburst was followed by a violent magnetic storm on July 16, may possibly have some significance.

As has already been mentioned, the reappearance of Spot A at

the Sun's eastern limb was heralded by a prominence at the same position angle. On plate 850 (July 6, 11^h 55^m) the facula surrounding the spot is shown projecting above the limb. On plate 857 (July 7, 11^h 19^m) the facula has entered the disc. The spot was probably exactly on the limb at this time, as a depression at the limb is distinctly shown on the photograph. The same thing is shown on plate 858. On July 8, 10^h 15^m, the large spot nucleus had advanced on to the disc (plate 862). No more photographs were secured until July 11, 10^h 8^m, when Spot A was well advanced on the Sun's surface. A comparison of plate 811 with plate 863 shows that Spot A and the group of faculæ preceding it greatly increased in size while on the invisible hemisphere. On July 11 this spot group was, with possibly one exception, the most important on the visible hemisphere. On June 20, just before the passage of the spot around the western limb, the group was inconspicuous, and of minor importance.

Plates 864, 865, 866 (the last taken July 11, 10^h 34^m) agree closely with 863, and record no disturbances or groups of faculæ at the eastern limb. Plate 867 (July 11, 12^h 21^m) shows an eruptive prominence at the eastern limb. Plate 868, taken 13^m later, seems to show some changes in the faculæ west of Spot A. Unfortunately no more photographs were secured until July 12, when plate 873, exposed at 11^h 35^m, showed that marked changes had taken place in the spot and in the faculæ just preceding it during the previous 23 hours. No faculæ were recorded at the eastern limb at this time.

From Father Sidgreaves' paper * we learn "that the magnets now remained generally quiet (after June 28) with the exception of some slight movements, the more noticeable taking place at early morning and at midnight of July 10th. The spot had reappeared on the Sun's visible disc on July 8th. On the 11th, the day Mr. Townsend observed the remarkable reversals of the C line in the spot at about 12.15 P. M., G. M. T., a single sharp upward movement, both on the declination and the horizontal force magnets, alone interrupted their otherwise quiescent state." It will be seen that while our records contain no photographs taken at the time of the disturbance witnessed by Mr. Townsend they show that a marked change took place in the spot and faculæ on the day in question. It does not seem unreasonable to connect this sudden movement of the magnets with the simultaneous disturbance in the spot.

Plate 874 was taken a few minutes later than 873, and shows

* ASTRONOMY AND ASTRO-PHYSICS, November, 1892, p. 818.

no changes. In plate 875, (July 12, 11^h 51^m) a faculous bridge seems to have formed over Spot A, but no other marked changes are shown. A marked disturbance of the declination magnet commenced almost simultaneously with the formation of the bridge.

This was the prelude to a violent magnetic storm, which continued on July 13 and 14. Plate 881 was taken at 11^h 36^m on July 13, and agrees with Plate 883, taken 25^m later, in showing that important changes in the faculæ surrounding Spot A took place during the preceding 24 hours, while the magnetic storm was in progress. Plate 884 was taken only 3^m later, but shows a very marked change during this brief interval in the faculæ near a spot in the southern hemisphere not far from the western limb. Just at this time there was a sudden movement of the declination magnet at the U. S. Naval Observatory. There were no faculæ at the eastern limb.

Plates 886 (2^h 34^m) and 889 (4^h 19^m) reveal no further important changes, but Plate 891 (July 14, 10^h 9^m) shows marked differences in all of the larger groups of faculæ. Plates 892, 893, 894, 895, 896, 897, 901 (the last taken at 3^h 55^m), have mainly a negative value in showing a state of comparative quiet in the various groups of spots and faculæ. Between 3^h 55^m and 4^h 8^m there was a great change in the form of a curiously shaped facula in the southern hemisphere. The declination magnet was quiet after 10 ^{h} A. M. until 3^h 40^m P. M., when there was a sudden fall, followed by slight oscillations lasting about an hour. The horizontal force magnet also was quite steady after noon, but at about 4^h P. M., the exact time of the sudden change noted above, the record shows a marked maximum.

We now come to the eruption of July 15, the various phases of which are shown in the accompanying plate. Some difficulty has been experienced in reproducing the photographs by the photogravure process, and the results by no means do justice to the original negatives. Unfortunately, the grain of the plate is brought out by the enlargement,* and the horizontal dark lines (due to dust on the slit of the spectroheliograph) could not be removed. In spite of their shortcomings, the photographs will serve to show the successive stages of a rare and important phenomenon. As I have already described this eruption,† it is unnecessary to enter into its details here. It evidently had its rise in the bridge shown in the first figure between the two umbræ,

* The photographs are on a scale of about 12 inches to the Sun's diameter.
† See ASTRONOMY AND ASTRO-PHYSICS, August, 1892, p. 611.

from a photograph taken at $11^h\ 8^m$. The hook-shaped form which had developed 12^m later is shown in the next figure. At $11^h\ 47^m$ the eruption was at its height, and the spot itself was hidden from view. The last figure is from a photograph taken at 2^h, when the eruption had subsided. A careful examination of the original negatives shows that the faculæ surrounding the spot were not changed in form by the disturbance, which, as I have before suggested, was probably a true eruption. The greater brightness of the faculæ in the last figure as compared with the first figure is probably not due to any effect of the eruption, but simply to the fact that the latter is the better photograph of the two, on account of a more careful adjustment of the spectroheliograph.

In *l'Astronomie* for September, four illustrations are given from drawings of the spot on July 15 by M. L. Rudaux. M. Rudaux's observations were made at Dauville, France, at $4^h\ 30^m$ P. M. (about $10^h\ 30^m$ A. M. Chicago M. T.). In his paper he says: "About $5^h\ 5^m$ ($11^h\ 5^m$), just as I had finished my drawing, the tongue of fire which traversed the large nucleus suddenly became brilliantly white; luminous points of an extraordinary intensity were visible at its surface, especially toward the base, and a less luminous and slightly diffuse border formed on the east side of this tongue. At the same instant, an equally brilliant luminosity appeared in the oval spot exactly in the place of the luminous bridge which had been visible there before." M. Rudaux goes on to describe the changes which ensued before $5^h\ 30^m$ ($11^h\ 30^m$), when his observations were unfortunately stopped by clouds. From his drawings it is evident that he was witness to only the earlier stages of the phenomenon. He speaks of a partial cessation of the eruption at $5^h\ 25^m$ ($11^h\ 25^m$) but of this I have no record. He also adds that the spot underwent no marked change in form.

The records of the Naval Observatory declination and vertical force magnets at the time of this remarkable outburst agree with those of Stonyhurst in showing not the slightest disturbance. The Naval Observatory trace of the horizontal force magnet being imperfect at this point I give Father Sidgreaves' statement that "there was, however, a slight trembling in the horizontal force magnet which was the prelude to the violent storm which set in and lasted over the 16th until midnight of the 17th."

Plate 915 (July 16, $10^h\ 44^m$) shows a great change in the faculæ around Spot A since the preceding day. Plates 916, 917, 18, 9921, 922, 924 (the last taken July 16, $3^h\ 22^m$) continue to

show changes, and prove that this region of the Sun was in a state of great activity at this time. No disturbances are recorded at the eastern limb of the Sun. The movements of magnets were very violent all day, the maximum in the case of the horizontal force magnet occurring about 2 P. M., and amounting, according to Father Sidgreaves, to 1° 34.73′.

It would be premature to attempt to draw any definite conclusions from the result of this inquiry, but two or three matters of interest may be pointed out. As the perturbations of terrestrial magnetism seem to synchronize closely with the activity of various groups of spots and faculæ indifferently situated in various parts of the visible solar surface, neither the "eastern limb theory" advocated by Veeder, nor the "central meridian theory" of Marchand, seems to receive any support. Nor can I agree with Father Sidgreaves that the supposition that particular classes of spots exercise a special magnetic influence has received any confirmation. I am inclined to believe, however, that M. Tacchini's explanation of terrestrial magnetic phenomena as the result of exceptional disturbances in prominences or faculæ on any part of the Sun's visible surface is slightly strengthened by the results here presented.

KENWOOD OBSERVATORY,
University of Chicago, Nov. 17, 1892.

ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

The 40-inch Telescope of the Yerkes Observatory.—The large discs of optical glass made by Mantois for the University of Southern California have been purchased by the University of Chicago. They are nearly 42 inches in diameter, and will allow of a clear aperture of 40 inches. The glass is said by Mr. Alvan Clark to be exceptionally good. Mr. Clark will shortly undertake the work of grinding the objective, which he has contracted to complete within eighteen months. The contract for the mounting will be let within a short time. The site of the Observatory is still undecided, but it will probably be several miles outside the city.

Unusual Appearance in a Sun-Spot.—On Sunday, August 21, at 5:35 P. M., my usual arrangements for solar observation by projection on a sheet of cardboard being completed, my attention was at once arrested by a remarkable appearance in an oval spot of moderate dimensions (in length not more than 40″ of arc), in longitude 276°, latitude 24° N. Between the umbra and penumbra was a band

of bright light exceeding the brightness of the faculæ then visible near the W. limb, although the spot was only about 32° from the central meridian.

Besides its brilliancy, which caught the eye at once, it was peculiar from the position of the light as regards the nucleus, being exterior to it rather than interior, such faculous light being not uncommon in the centre of a spot containing several nuclei, or in the form of luminous bridges between nuclei, which are on the point of separation, but not on the outer side.

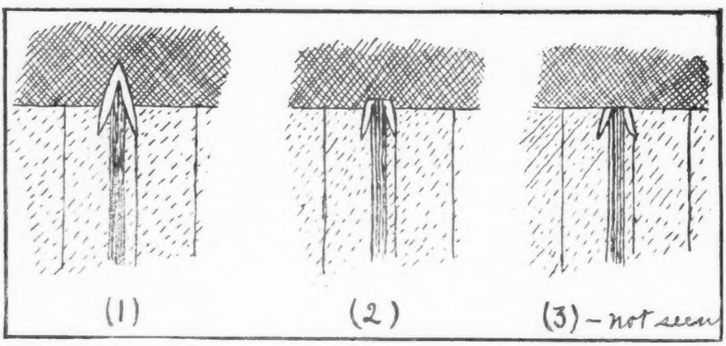
The lustre continued without diminution until 6:5 P. M., after which time passing clouds and poor definition prevented any further observation.

At 7 A. M. on the following day it had disappeared. The only noteworthy alteration in the spot was a separation of a small portion of the penumbra to the N., thus not precisely in the same direction as the band of light, which lay towards the W. I much hope that this appearance may not have been of so transitory a nature as to have escaped the observation of other members of our Solar Section, and that some of the daily photographs taken at Greenwich or elsewhere may be found to confirm it.—*Jour. B. A. A.*, 1892, p. 504.

(MISS) E. BROWN.

Behavior of the Arrowhead in the C line in a Solar Eclipse.—When the slit of a spectroscope is placed radially across the image of the Sun's limb the C and F lines at the boundary of the Sun's spectrum and for a short distance beyond consist of a dark line narrowing down to a point, with a bright line on each side; these two bright lines being joined above the point of the dark line and extending down into the spectrum of the Sun's disc. The whole constitutes the familiar "arrowhead."

In the partial solar eclipse of Oct. 20, just after the observation of first contact, the slit of the spectroscope was placed radially at a point of the Sun's limb which the Moon's advancing edge was about to obscure, with the object of studying the behavior of the arrowhead in the C line. As the Moon advanced the arrowhead was gradually truncated until the two "barbs" were left separated with a dark space between them; but when they were cut down to about the edge of the bright spectrum, the two points of the barbs which extend down into the spectrum vanished together and instantly. The observation was repeated with care a number of times.



In the figure (1) shows the whole arrowhead; (2) was each time easily seen; (3) was not seen at all, though carefully looked for. As nearly as I could judge the time when the barbs disappeared was the instant when the truncation of the

arrowhead reached the edge of the bright spectrum. The observations were made with the Brashear grating spectroscope on the 23-inch equatorial of the Halsted Observatory. TAYLOR REED.

Princeton, N. J., Oct. 28.

Do Large Telescopes Pay?—Apropos to the announcement that the University of Chicago will have a telescope of forty or more inches aperture, Mr. John Ritchie, Jr., communicates an article to the *Boston Commonwealth* on the subject "Do Large Telescopes Pay?" which is more remarkable for its vigor than for the breadth of the author's views disclosed in it. The question is not, of course, whether large telescopes are to be regarded as successful financial enterprises, but whether the results achieved by them are sufficiently important, in a scientific sense, to justify the expense of their construction. Mr. Ritchie answers this question in the negative, fortifying his position by a somewhat lengthy discussion of the standing of various observatories and the relative merits of well-known observers. For reasons which have a proverbial basis, we prefer not to enter into these personal questions, although we may remark that some persons may be inclined to dissent from Mr. Ritchie's opinion; but the relative importance of various kinds of astronomical work, which is necessarily involved in the discussion, is a subject which may be considered without hesitation. It necessarily rests on the correctness of personal judgment, and is therefore unavoidably affected by personal bias; for where can a man be found whose views are so broad, and, we may say, whose vision is so prophetic, that he can assign to facts their proper relative values, and tabulate them in the order of their importance? We once heard an eminent investigator casually refer to a certain discovery in physics as one of trifling value, while some weeks later an equally competent authority wrote of it in one of the physical journals as a discovery of great importance. Every specialist is naturally inclined to attribute more than ordinary importance to the line of study in which he is himself engaged, and moreover, a value which is in some degree fictitious is attached to whatever is difficult to ascertain.

Mr. Ritchie regards the discovery of a fifth satellite of Jupiter as of little value, probably because it was made by so brutal a method as that of simple visual observation with a large telescope. If the satellite had been found by studying the possible perturbations of the other satellites, he would doubtless have considered the discovery one of the most splendid triumphs of the age. This view has much in its favor, but it places the means before the end. The satellite has been found to exist; we fail to see how the simplicity of the method can so completely destroy the importance of the fact.

The only sphere of usefulness which Mr. Ritchie will allow great telescopes is the observation of objects beyond the range of small telescopes, and to such objects he thinks their use should be restricted. The absurdity of this view does not require pointing out,—certainly not to anyone who has used a large telescope. The same advantages (greater light, magnification, and resolving power) which make the large instrument superior to the small one in the case of very faint and minute objects, still remain a source of superiority for objects that are brighter. We should be inclined to reverse the rule in the apportionment of the field, and confine the use of the small telescope to work in which rapidity is the chief consideration. It is, of course, understood that reference is here made to the equatorial telescope, the superiority of the small instrument, when used with graduated circles for observations of precision, being undisputed. From Mr. Ritchie's point of view it would seem that the field of employment for an equa-

torial of any kind is a very limited one. If the discovery of a new satellite is not of importance, neither, *a fortiori*, is the observation of satellites already known to exist. An asteroid can hardly outrank a satellite, and it is not easy to see (from the same standpoint) why comets should be assigned to a higher place in the scale. Double stars are also held in low esteem, and as for celestial spectroscopy, and the whole modern development of astronomy in the direction of astrophysics, Mr. Ritchie either does not consider them worthy of mention, or he is unaware of their existence.

A defence of these subjects does not seem to be necessary. A paragraph of Mr. Ritchie's leads us to remark, however, that their scientific importance is not diminished by the fact that they are also of popular interest. But the spectroscope is not only the key which unlocks the constitution of the stars; it has taken its place among time-honored tools of the astronomer as an instrument of precision. For the purposes to which it is applied, the demand is always for more light, and light can be obtained only by constructing large telescopes. It is true that some of the most important investigations (the Potsdam measures of motions in the line of sight, for instance), have been made with comparatively small instruments, but in these cases the work was not done with small telescopes because they were better than large ones, but because larger telescopes were not to be had. That such skillful astronomers as Professor Vogel and Professor Pickering are desirous of securing large telescopes may be regarded as indicating the opinion of the best authorities on this subject.

The part of Mr. Ritchie's article which relates to the insufficient endowment of large telescopes must meet with entire approval. An observatory without the means of carrying on observations is as useless as a manufacturing plant without workmen. We do not anticipate that the Chicago Observatory will be left in such a plight. In regard to the facts of some of the cases given as examples we moreover have reason to think that Mr. Ritchie has been misinformed.

The above remarks have been made not so much in the way of argument as for the purpose of showing that the question has another side, which cannot be ignored, and that it is not to be settled by the off-hand opinion of a single person. As an able defence of the great telescope, we commend the following note by Professor E. S. Holden in the November *Forum:*

"I should like to call attention to the fact that the history of the great telescopes at Mount Hamilton and at Washington will serve to lay away finally a widely published opinion which we used to hear repeated every few weeks—namely, that great telescopes are of little use. The work of these two great telescopes (not to speak of many others) has conclusively shown their great superiority over less powerful instruments in every field of astronomy, in the observations of planets, nebulæ, stars, comets, satellites, in spectroscopy, and also in those departments of astronomical photography for which they are adapted. Smaller instruments have their appropriate fields, and in some of these they will always be more convenient than larger ones. But the great telescope, when properly used, is and will always be pre-eminent. The proof is easy to give, and I trust that we shall not hear any more idle detraction of the work of our great instrument-makers, the Clarks, or their European rivals."

It will be observed that Professor Holden does not even regard the question as open. K.

A New Combined Visual and Photographic Objective.—In making the new twelve-inch objective for the Dudley Observatory, Mr. Brashear is carrying out a plan which was long ago developed mathematically by Professor Hastings of Yale University. The crown glass lens is mounted in a cell fixed to the end of the telescope tube, and two flint glass lenses are provided, each in a separate cell,

which serve to form with the crown lens either a visual or a photographic combination. The flint lens is therefore on the outside. As in both cases the lenses are in contact, but must not be subjected to the least strain, very careful mechanical work is required in fitting the cells. Mr. Brashear has also added some very simple but ingenious appliances by which the exchange of cells can readily be made by one person.

This form is not so simple as the objective with single reversible crown lens, but it gives a more perfect correction for color and spherical aberration. It is well known to the practical optician, and is also demonstrable mathematically, that the reversible crown lens cannot meet both requirements in a perfectly satisfactory manner. In making the necessary compromise the greater sacrifice is generally thrown on the photographic arrangement, as the one in which errors are least noticeable. In the new form the definition of each combination is equal to that of a specially constructed objective.

If the glass-makers could furnish glass with the requisite optical properties, both combinations could be made to have the same focal length. This may possibly be the next improvement to be looked for. The advantages of the new form over the visual objective with photographic corrector are obviously less loss of light by reflection and absorption, and greater lightness.

The Spectrum of Holmes' Comet.—On the evening of Nov. 16, I examined the spectrum of Holmes' comet, using a spectroscope of 1.12 inches effective aperture attached to the 13-inch equatorial. The spectroscope carried a single light flint prism, and the power of the observing telescope was about 6.

The spectrum was continuous, and fairly bright. It extended from D to a point half way between F and G, the maximum brightness being a little below *b*. With the most careful attention I could see no lines. A somewhat brighter streak running through the spectrum was due to the nucleus of the comet.

By means of a comparison prism I threw in the spectrum of a piece of white paper, illuminated by a distant argand lamp. Both spectra were of about the same brightness. That of the comet was somewhat the longer, and as a whole it lay farther toward the violet; otherwise they were very much alike. These are just the appearances that we should expect if the comet shines entirely by reflected sunlight.

Cloudy weather has prevented any attempt to photograph the spectrum.

J. E. Keeler.

Professor Seeliger's Explanation of Nova Aurigæ.—The hypothesis which Professor Seeliger has advanced to account for the phenomena attending the appearance of new stars, explains all except the latest observations of Nova Aurigæ. It is sufficiently flexible to include a great variety of possible appearances, and it avoids difficulties which are quite serious when viewed from the standpoint of other hypotheses. Nevertheless recent unexpected developments in the case of Nova Aurigæ show that it is open to grave and perhaps even fatal objections. In our present number we give a translation of Professor Seeliger's article in the *Astronomische Nachrichten*, which, it will be observed, was written before the reappearance of the star. By far the most complete and important observations which have been made since that time are those of Professor Campbell at the Lick Observatory, and their bearing on Professor Seeliger's views is a matter of great interest. Some of the earlier observations, also, are not quite completely explained by the latter, as we may first point out. According to this hypothesis, the

dark lines observed in the spectrum of Nova Aurigæ during the winter had their origin in a gas stratum which partook of the motion of the solid body, and hence their observed displacement is a measure of the motion of the star in the line of sight. The velocity thus determined is about 300 miles per second, and that of the star on entering the cosmical cloud must therefore have been equal to or greater than this. An initial velocity of this magnitude is certainly surprising, but it is not impossible, or even without a parallel, as the isolated star 1830 Groombridge is moving at a minimum rate of 200 miles per second, and actually perhaps several times faster than this. New stars are, moreover, exceptional phenomena, and it is rather to be expected that their attending circumstances should be exceptional.

But we have now to point out some difficulties. As the dark lines were displaced toward the violet, the star was approaching the Earth. The gaseous matter giving the bright lines was receding from the Earth at the rate of over 400 miles per second. It is not clear how matter detached from the solid body could have so great a velocity. On the other hand, if the light came from particles of the nebulous cloud heated by friction, or by radiation from the incandescent surface of the body, one would expect that the most swiftly moving particles would be those most intensely heated; but according to observation, the bright lines were brightest and most sharply defined on the upper side, which was that least displaced, this appearance indicating a low limiting velocity for the brightest particles.

These are perhaps not serious objections, but how are we to account for the observed fact that after the reappearance of the star the bright lines in its spectrum were displaced toward the violet, whereas the bright-line spectrum during the winter was displaced toward the red? It is true that the two spectra do not seem to be very closely related, but some lines, notably those of hydrogen, are common to both, and it is not easy to see how such a change in the direction of their displacement can be accounted for on any hypothesis involving rectilinear motion only. The slackening in the rate of approach which Professor Campbell has recently observed, and which has not been accompanied by any outburst of light, is also incompatible with rectilinear motion. The difficulty might be met by calling to our aid some center of attraction, as a dark body within the nebula (although the nearly constant velocity during the winter would remain unexplained) but in that case the hypothesis would lose its extreme simplicity. Professor Seeliger's criticism of former hypotheses is of great value, and its force remains, whether his own explanation is regarded as tenable or not. We have not yet seen the end of Nova Aurigæ, and a complete solution of the difficult problems which it has presented to us may have to wait for the light of future investigations.

A Small Spectroscope by Mr. Brashear.—Mr. Brashear has recently designed a small but high-class spectroscope which is light enough to be used on telescopes of from four to eight inches aperture, and which can be sold at a price that will bring it within the reach of amateurs. It has telescopes of 8 inches focus and $\frac{3}{4}$ inch aperture, and it can be used with either a prism or a grating. All necessary attachments are provided, and some luxuries. Another instrument designed especially for amateurs is a small position micrometer.

On the Mass of the Earth's Atmosphere.—M. Mascart, with his usual lucidity, has revised Laplace's computation of the mass of the atmosphere. Laplace obtained his well known barometric formula by assuming that

$$\rho = \rho_0 \, e^{-\frac{R}{H}s}$$

where ρ_0 = density of atmosphere at sea level.

R = radius of Earth.

H = height of the homogeneous atmosphere [density = ρ_0] whose pressure will just balance that of the barometer.

h = height above sea level.

$s = \dfrac{h}{R + h}$.

But this law makes the mass of the atmosphere infinite and must, therefore, be discarded.

Mascart proceeds to take account of the variation of gravity with altitude and also of the fact that the bounding spherical surface increases as one goes from the surface of the Earth outwards. But he distinctly disregards the complication introduced by the rotation of the Earth on its axis. His method is to assume, using the notation above,

$$\rho = \rho_0 \, f(s)$$

and then find the most probable form of $f(s)$. The considerations which determine the form of this function are three in number, viz.:

(1) The mass of the Earth's atmosphere must be finite.

(2) The value of $\frac{H}{R}$ must be small.

(3) The function must become unity for the surface of the Earth, *i. e.*, for $s = 0$; it must decrease continuously as h increases and become zero when $h = \infty$.

These lead, not with mathematical rigor, but with a high degree of probability, to the following expression for the density at any point

$$\rho = \rho_0 \, (1 - s)^4 \, e^{-\alpha s}$$

where α is a constant to be determined by barometric observations at elevations as different as possible.

Solving for α,

$$\alpha = \frac{1}{s} \log (1 - s^4) \frac{\rho_0}{\rho}$$

Data obtained on Mt. Blanc, Pike's Peak, and the Sonnblick give

$$\alpha = 660. \text{ approx.}$$

This value is next employed to get the mass of the atmosphere by integration, in the usual manner

$$\text{Mass} = \int_0^\infty 4\pi(R + h)^2 \rho \, dh = 4\pi R^3 \rho_0 \int_0^1 \frac{f(s)}{(1-s)^4} ds.$$

$$= \text{constant} \, . \int_0^1 e^{-\alpha s} \, ds.$$

Performing the quadrature one sees that Mascart's statement of the law of variation of density with altitude is equivalent to saying that the ratio of the mass of air above any height, h, to the total mass is $e^{-\alpha s}$.

From this integral the author also readily derives the height of a homogeneous atmosphere defined as follows, *viz.*: *one whose density is constant and equal to ρ_0, and whose mass is equal to the integral above.*

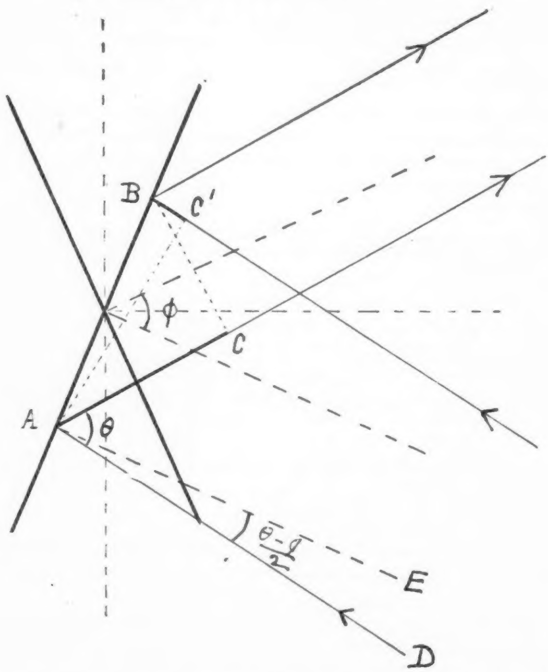
This definition implies simply that in defining the homogeneous atmosphere one takes into account the diminution of gravity at high altitudes. The result is somewhat surprising. The height thus obtained is one-sixth greater than that of the homogeneous atmosphere as ordinarily defined, *viz.*: *the height of atmosphere of density ρ_0 which will produce the same pressure as that indicated by the*

barometer at sea level. These values are confessedly approximate, as, indeed, all values obtained by extrapolation must be. One cannot, however, doubt that the corrections of M. Mascart are in the right direction and very much larger than would have been imagined without rigid computation. The author adds the important remark that although Laplace's expression for density leads to an infinite mass, the refraction formulæ of Laplace and Bessel still hold good since they are derived from the consideration of a column of air of constant cross-section.

The original paper of Mascart will be found in the *Journal de Physique* for March of the present year.

A New Proof of a Fundamental Equation of the Spectrometer.—The following demonstration, by Mr. Robert R. Tatnall, is certainly neat and apparently new. The method he employs for measuring wave-lengths is that in which the telescope and collimator are firmly clamped at a fixed angle with each other.

Under these conditions, the grating was employed successively in the two positions in which it gave the same Fraunhofer line first in a left-hand spectrum and then in the right-hand spectrum of the same order.



From the principle of the reversibility of light rays it follows that the two positions of the grating will be symmetrical about the bisectrix of the angle between collimator and telescope. Let us call this angle θ while we denote by φ the angle between the two positions of the grating.

In the figure, consider either position of the grating, say AB; and let the distance AB represent the grating space, s.

The retardation of paths will then be AC — BC′ and

$$AC - BC' = s(\sin C\hat{B}A - \sin B\hat{A}C')$$

But by symmetry,

$$C'\hat{A}E = D\hat{A}E = \frac{\theta - \varphi}{2}$$

Also

$$C\hat{B}A = C\hat{A}E = C\hat{A}D - D\hat{A}E$$
$$= \theta - \frac{\theta - \varphi}{2}$$
$$= \frac{\theta + \varphi}{2}$$

Hence, if λ = required wave-length and $\varkappa$ = order of spectrum

$$\varkappa\lambda = s\left(\sin\frac{\theta + \varphi}{2} - \sin\frac{\theta - \varphi}{2}\right)$$

or

$$\lambda = \frac{s}{\varkappa} \cdot \cos\frac{\theta}{2} \cdot \sin\frac{\varphi}{2}$$

On a Simple Method for Obtaining the Color Curve of a Lens.—Having at my disposal one of Rowland's deep concave gratings, I found it very useful for studying the achromatism of lenses in the following manner. The method is essentially that of Hasselberg [*Melanges Math. et Astron., t. VI, p. 669 (1888)*,] who uses a prism to produce bright line spectra in the focal plane of the view-telescope and then observes these bright lines with the lens in question.

The only objection to this process is that, in order to obtain the required color curve, one has either to know or neglect the color curve of the lens in the view-telescope, an objection which is not serious, of course, for long focus lenses such as are used in astronomical telescopes.

Since the concave grating is perfectly achromatic, it avoids this difficulty and permits one to use the method for measuring short-focus lenses. In this way, I have examined several photographic objectives. The grating is collimated with the direction of the ways of an optical bench and then fixed. The slit is mounted after the manner of Waterhouse [*Mem. Soc. Spettroscopisti Ital., Vol. 18, pp. 14-16. 1889.*] so as to rotate in a circle having for its center the point midway between the grating and its center of curvature.

The various bright lines of metallic spectra were then brought to focus strictly at the center of curvature of the grating and were examined in succession by the photographic objective mounted on the bench.

Another method by which one may avoid the chromatic aberration of a view-telescope is to employ a candle (or, better still, a brighter source) to produce a continuous spectrum, either by prism or grating, and then suspend, approximately in the focal plane, a pair of fine spider webs with small weights attached so as to bring the webs to strict parallelism. The distance at which the image of the spider webs will appear, depends, other things being equal, upon the wave-length of the light with which the webs are illuminated.

To prevent air currents blowing the webs out of a fixed plane, it is well to immerse the stretching weights in a small cup of oil.

Having obtained a sharp object of any desired color by either of the above methods, one proceeds to determine the corresponding focal length. Bessel's formula is probably the best; but if one has a good micrometer eyepiece he may compare the size of the image produced by the lens in one of its symmetrical positions with that produced by the lens in the other symmetrical position, and thus rid himself of the troublesome measurement of distance of image from object.

If, in any particular lens, one has convinced himself that the separation of the principal planes does not vary appreciably with the wave length, the following method is quick and convenient.

Mount the observing eyepiece in a graduated drawtube. Place the lens in any convenient position on the bench. Call the distance of its first principal plane from the object s: and let i denote the distance from the second principal plane to the image. If f be the focal length for light of any wave-length λ, *Newton's Rule* gives

$$(s - f)(i - f) = f^2$$

whence

$$df = \left(\frac{s}{s+i}\right) di.$$

Now di can be read off the draw tube as the spider webs are illuminated by one color after another while comparatively rough measurements of s and i will give the factor $s/s+i$ with required accuracy. All that remains is to plot df as a function of λ.

HENRY CREW.

Nova Aurigæ.—The reappearance of Nova Aurigæ seems to have been noticed almost simultaneously on both sides of the Atlantic At Mt. Hamilton the star was observed to have augmented in brightness on August 17, and in England Mr. Henry Corder made the same observation on August 19. Earlier discovery was prevented by the unfavorable position of the star. On the ground of Professor Seeliger's hypothesis no special importance would attach to the photometric observations of Nova Aurigæ, the fluctuations of brightness being indicative of nothing more than casual variations of density in a cosmical cloud.

A Translation of Scheiner's *Die Spectralanalyse der Gestirne.*—Messrs. Ginn & Company of Boston announce for early publication a translation of Dr. Scheiner's well-known work by Prof. E. B. Frost of Dartmouth College. They have established a Department of Special Publication, which, according to a recent circular "will prepare and send out to all likely to be interested detailed prospectuses of works of this class that may be offered us, and invite subscriptions or pledges for a specified number of copies. If the responses are sufficiently encouraging, the book will be published." We sincerely hope that in the case of the present work the responses will be "sufficiently encouraging," for the need of an English edition has been widely recognized. Professor Frost's stay of two years at Potsdam, and his intimate acquaintance with Dr. Scheiner, give him special advantages in undertaking the translation, and we look f r a book of great value. We give below the prospectus issued by Messrs. Ginn & Co.

A TRANSLATION OF DR. SCHEINER'S DIE SPECTRAL-ANALYSE DER GESTIRNE. By Professor EDWIN B. FROST *of Dartmouth College.*

This work, by one of the brightest astronomers of the Royal Observatory at Potsdam, was published in the autumn of 1890, and has already made itself the standard treatise on Astronomical Spectroscopy.

The *aim* of the work has been to provide a thoroughly scientific handbook, which should explain the most practical and modern methods of research in observatory and laboratory, and should present a clear account of the present state of our knowledge of the constitution, physical condition and motions of the heavenly bodies, in so far as these are revealed by spectroscopic researches.

A simple and straightforward style of expression and development has been followed by the author, and will be preserved by the translator, so that it is hoped that the physical interpretation of the principles and theorems discussed will be entirely clear to those who do not care to, or are unable to follow out, the mathematical demonstrations.

The subject matter of the work is divided into three parts:—

I. Spectroscopic Apparatus.
II. Spectral Theories.
III. Results of Spectroscopic Observations of the Heavenly Bodies.

To these is added a fourth part containing a number of extensive and useful tables of wave-lengths of lines of the solar spectrum, catalogues of stars with special types of spectra, and a full bibliography of the subject, which will be brought down to 1893.

The edition in English will be finely illustrated with the 75 woodcuts and lithographed plates of the original, with some additions. The illustrations are, it should be said, almost wholly new, and not reproductions of the traditional figures which have so long appeared in all books touching upon this subject.

A number of additions and some changes will be made in the translation to adapt it more nearly to English and American readers.

The cordial support and co-operation of the author is assured

The volume will comprise about 350 pages of text and 100 pages of tables and bibliography. The price will be set at $5.00. It is hoped that it may be ready in about a year.

It is expected that this Treatise on Astronomical Spectroscopy will be found of constant and specific service to —

The professional and amateur worker in astro-physics and astronomy, for the practical information and useful data it contains;

The instructor and student in physical laboratories, for its treatment of the solar spectrum, spectrometers, prisms and gratings, and for its tables;

The advanced classes in higher institutions, for a text book; and

The lower classes, for a book of reference;

Teachers of elementary astronomy and physics generally, who wish to have at hand a reliable source of information extending beyond that given in their text books, and to the increasing body of

Amateurs, of both sexes, who are in America and England manifesting their interest in the progress of the science by their active participation in the work of the various scientific societies.

Address GINN & COMPANY, Boston.

Recent Spectroscopic Determinations.—The letter printed below appeared in *Nature*, Sept. 29, 1892, and refers to an important article by Professor Michelson which will be found on another page:

In the September number of the *Philosophical Magazine* Mr. Michelson has published determinations, by a most interesting method, of very close double and multiple lines. In any attempt to interpret his results, it is necessary to bear in mind the profound modifications which the internal motions of a gas—the rectilinear motions of the molecules between their encounters, as well as the motions going on within each molecule—had undergone within the Geisler's tubes upon which he experimented.

In a gas under ordinary circumstances the rectilinear journeys of the molecules take place indifferently in all directions, and where this is the case it follows from the well-known relation between the surface of a sphere and that of its circumscribing cylinder, that the effect of the velocities which happen to lie between v and $v + \delta v$ is to substitute for each line of the spectrum of the gas a band of uniform intensity and without nebulous edges, the width of which can be calculated. This width, for example, is .04 of an Ångström or Rowland unit (the tenth-metre), in the yellow part of the spectrum and for velocities of the molecules which lie in the neighborhood of two kilometres per second, which is about the average velocity of molecules of hydrogen at atmospheric temperatures. Hence with all the velocities that prevail among the molecules, the effect of the rectilinear motions under ordinary circumstances is that each line will be symmetrically widened and rendered nebulous. To this effect Mr. Michelson calls attention.

But in the residual gas of a Geisler's tube through which electricity is passing, the case is altogether different. Here the rectilinear motions of the molecules are not alike in all directions, but preponderate in some; a state of things which must at least double the lines, and may introduce greater complications.

Moreover, different lines may be differently affected, since the behavior of the gas varies according to its position between the electrodes; as is evidenced by the observed differences in the form and coloring of the striæ, &c., in the several parts of a Geisler's tube.

We must also be on our guard in another respect, when we attempt to interpret the results, since the distribution of the heat energy of a gas between the rectilinear motions of its molecules and the motions within the molecules, which in the case of ordinary gas is a fixed ratio, is certainly largely departed from in gas through which electricity is passing. Until the laws of the new distribution are understood, the temperature of the gas, judged of by its behavior to neighboring bodies, will give us little information

It is to such events as are referred to above, or others which like them may arise from the special circumstances under which the vapor of sodium was in Mr. Michelson's experiments, that we must apparently turn for an explanation of the doubling of the constituents of the principal pair of sodium lines which he has detected; since he found that "the width of the lines, their distances apart, and their relative intensities vary rapidly with changes in temperature and pressure."

The method of investigation which Mr. Michelson has so successfully applied appears to be by far the most searching means yet discovered of experimentally investigating the intricate and obscure phenomena which present themselves in Geisler's tubes, and we seem justified in hoping for great results from it.

G. JOHNSTONE STONEY.

9 Palmerston Park, Dublin, September 22.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR JANUARY, 1893.

H. C. WILSON.

Mercury during the first few days of January will be visible to the naked eye in the morning. One should look toward the east at 7 A. M., a little above the point where the Sun will rise.

Venus will be in the same part of the heavens, but about 15° toward the west. There will be no difficulty in seeing Venus with the naked eye during this month, but telescopic observations will be difficult, because of the low altitude of the planet.

Mars will be visible in the evening until 11 P. M. The best time for observing the planet is just after Sunset. The disk of Mars will be less than 8″ in diameter during the greater part of the month so that we need not expect to see much of detail on its surface. At 10 P. M. Jan. 25 there will be a conjunction of Mars and Jupiter. Mars will pass 1° 36′ to the north of Jupiter on its eastward course. A telescope with low power will at that time show both planets in the field of view at once. It will be an excellent time for comparing the light of the two planets.

Jupiter will be at quadrature 90° east from the Sun, Jan. 5. On Jan. 23 at 6^h 43^m P. M., central time, there will be a close conjunction of Jupiter and the Moon. As seen from the center of the Earth Jupiter would then be only 6′ north of the Moon's center. In the southern part of the United States, Mexico, Central America and the greater part of South America, there will be an occultation of Jupiter. In latitudes north of 38° parallax will throw the Moon to the south of Jupiter.

Since our last notes were written, Professor Ormond Stone has published, in the *Astronomical Journal* No. 277, micrometric observations of the new satellite of Jupiter, made by himself with the 26-inch equatorial of the Leander McCormick Observatory on the night of Oct. 18. Professor G. W. Hough also has reported that he was able to see the new satellite with the 18-inch equatorial of Dearborn Observatory. Professor Barnard, the discoverer, gives the period of the fifth satellite as 11^h 57^m 20.5^s, and its mean distance from the planet's center as 112,510 miles (*Astr. Jour.* No. 277).

We presume it is unnecessary to tell many of our readers where the planets Jupiter and Mars are, but for the sake of any who may not know we will say that they are the two bright stars which we see towards the south and about half way up to the zenith in the early evening. Both exceed in brilliancy any other stars in the evening sky. Jupiter is white, while Mars is red.

Saturn will be at quadrature 90° west of the Sun Jan. 12. This planet will be in good position for observation in the morning during January. It may be easily recognized by its position in the center of the constellation Virgo and its bright yellow color. There will be a conjunction of Saturn with the Moon at 2^h 15^m A. M., Jan. 6. This will produce an occultation of the planet as seen from South America.

Uranus will be at quadrature, 90° west from the Sun, Jan. 29, and may be observed best at from 4 to 6 A. M. This planet is in the constellation Libra a little west of the bright star α. It may be recognized with a telescope of moderate power, by its dull green disk.

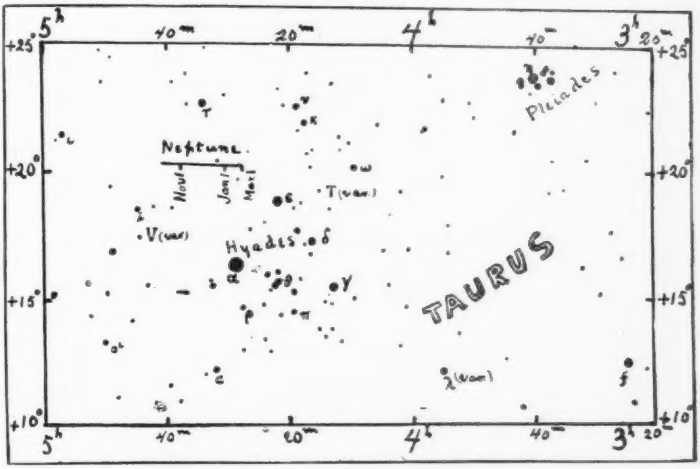


CHART OF NEPTUNE'S POSITION IN THE CONSTELLATION TAURUS.

Neptune will be in excellent position for observation during January. The accompanying chart will indicate where this planet should be looked for. It cannot be recognized by its disc except with large telescopes. The best way for an amateur to find it will be to make a careful chart of all the stars seen in this region and note from night to night which star changes its position. Neptune will be in conjunction with the Moon, 4° 37′ south, Jan. 27 at 9^h 36^m A. M.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
			MERCURY.		
Jan. 5	17 31.3	− 22 06	5 59 A. M.	10 29.5 A. M.	3 00 P. M.
15	18 29.0	− 23 29	6 25 "	10 47.5 "	3 11 "
25	19 33.6	− 23 01	6 47 "	11 12.7 "	3 38 "
			VENUS.		
Jan. 5	17 04.8	− 21 45	5 31 A. M.	10 02.8 A. M.	2 34 P. M.
15	17 58.3	− 22 48	5 50 "	10 16.9 "	2 43 "
25	18 52.4	− 22 42	6 05 "	10 31.7 "	2 59 "
			MARS.		
Jan. 5	0 21.7	+ 2 17	11 06 A. M.	5 18.6 P. M.	11 31 P. M.
15	0 45.7	+ 5 04	10 40 "	5 03.2 "	11 27 "
25	1 10.0	+ 7 47	10 14 "	4 48.2 "	11 22 "
			JUPITER.		
Jan. 5	1 01.9	+ 5 13	11 35 A. M.	5 58.6 P. M.	12 23 A. M.
15	1 05.7	+ 5 40	10 57 "	5 23.2 "	11 49 P. M.
25	1 10.5	+ 6 12	10 21 "	4 48.6 "	11 16 "
			SATURN.		
Jan. 5	12 50.2	− 2 45	11 52 P. M.	5 45.0 A. M.	11 38 A. M.
15	12 50.9	− 2 47	11 13 "	5 06.4 "	11 00 "
25	12 50.9	− 2 44	10 34 "	4 27.1 "	10 20 "
			URANUS.		
Jan. 5	14 31.0	− 14 24	2 25 A. M.	7 29.7 A. M.	12 35 P. M.
15	14 32.2	− 14 30	1 47 "	6 51.5 "	11 56 A. M.
25	14 33.1	− 14 34	1 08 "	6 13.0 "	11 18 "

NEPTUNE.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Jan. 5......	4 30.1	+ 20 14	1 58 P. M.	9 26.3 P. M.	4 55 A. M.
15......	4 29.3	+ 20 13	1 18 "	8 46.2 "	4 15 "
25......	4 28.7	+ 20 12	12 38 "	8 06.2 "	3 35 "

THE SUN.

Date. 1893.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Jan. 5......	19 08.2	− 22 32	7 37 A. M.	12 05.9 P. M.	4 35 P. M.
15.....	19 51.6	− 20 59	7 33 "	12 09.9 "	4 46 "
25......	20 33.8	− 18 46	7 26 "	12 12.7 "	5 00 "

Configuration of Jupiter's Satellites at 8h p. m. Central Time.

Jan.		Jan.		Jan.	
1	4 2 ○ 1 3	11	3 2 ○ 1 4	21	4 1 2 ○ 3
2	4 3 ○ 2 ●	12	3 1 ○ 4 ●	22	4 2 ○ 1 3
3	4 3 1 ○ 2	13	○ 3 1 2 4	23	4 1 ○ 3 2
4	4 3 2 ○ 1	14	1 2 ○ 3 4	24	4 3 ○ 1 2
5	4 1 3 ○ 2	15	2 ○ 1 3 4	25	3 2 4 ○ ●
6	4 ○ 1 3 2	16	1 ○ 3 2 4	26	3 1 2 ○ 4
7	4 2 1 ○ 3	17	♃ ♃ 3 ○ 2	27	○ 3 1 2 4
8	2 4 ○ 1 3	18	3 4 2 ○ 1	28	♃ 1 ○ 3 4
9	♃ ○ 4 2 ●	19	4 3 1 2 ○	29	2 1 ○ 3 4
10	3 1 ○ 2 4	20	4 ○ 3 1 2	30	1 ○ 2 3 4
				31	3 ○ 1 2 4

Phenomena of Jupiter's Satellites.

1893.	h	m					h	m			
Jan. 1	9	54 P. M.	I	Sh. In.		17	6	54 "	I	Tr. In.
2	5	06 "	III	Tr. Eg.			8	14 "	I	Sh. In.
	5	53 "	I	Oc. Dis.			9	09 "	I	Tr. Eg.
	8	17 "	III	Sh. In.		18	7	46 "	I	Ec. Re.
	9	25 "	I	Ec. Re.		19	4	56 "	I	Sh. Eg.
3	5	16 "	I	Tr. Eg.			8	47 "	II	Oc. Dis.
	6	36 "	I	Sh. Eg.		20	6	26 "	III	Ec. Dis.
	9	18 "	II	Tr. In.			7	14 "	III	Ec. Re.
5	6	04 "	II	Oc. Re.		21	6	33 "	II	Tr. Eg.
	6	18 "	II	Ec. Dis.			6	39 "	II	Sh. In.
	8	39 "	II	Ec. Re.			9	06 "	II	Sh. Eg.
9	6	40 "	III	Tr. In.		24	8	52 "	I	Tr. In.
	7	49 "	I	Oc. Dis.		25	6	13 "	I	Oc. Dis.
	9	09 "	III	Tr. Eg.		26	4	39 "	I	Sh. In.
10	4	57 "	I	Tr. In.			5	36 "	I	Tr. Eg.
	6	19 "	I	Sh. In.			6	52 "	I	Sh. Eg.
	7	12 "	I	Tr. Eg.		27	4	58 "	III	Oc. Dis.
	8	31 "	I	Sh. Eg.			7	27 "	III	Oc. Re.
11	5	50 "	I	Ec. Re.		28	6	42 "	II	Tr. In.
12	6	07 "	II	Oc. Dis.			9	16 "	II	Tr. Eg.
	8	42 "	II	Oc. Re.			9	17 "	II	Sh. In.
	8	55 "	II	Ec. Dis.		30	5	49 "	II	Ec. Re.
14	6	28 "	II	Sh. Eg.						

Phases and Aspects of the Moon.

		d	h m	
Full Moon..	Jan.	2	7 41	A. M.
Last Quarter...	"	9	4 28	P. M.
Apogee..	"	12	1 00	A. M.
New Moon...	"	17	7 28	P. M.
First Quarter...	"	25	12 27	A. M.
Perigee..	"	27	7 36	P. M.
Full Moon..	"	31	8 11	"

Occultations Visible at Washington.

Date 1893.	Star's Name.	Magnitude.	Immersion Washington M. T. h	m	Angle f'm N pt. °	Emersion Washington M. T. h	m	Angle f'm N pt. °	Duration. h	m
Jan. 7	10 Virginis	6.4	11	40	121	12	45	303	1	05
8	38 Virginis	6.2	11	36	64	12	11	356	0	34
11	ι^1 Libræ	5.0	15	24	156	16	21	268	0	57
11	ι^2 Libræ	6.5	15	41	93	16	45	333	1	04
14	3 Sagittarii	4.6	16	08	104	17	09	287	1	00
22	10 Ceti	6.2	8	53	81	9	48	220	0	55
25	50 Arietis	6.8	7	51	77	9	07	230	1	16
25	54 Arietis	6.3	12	10	62	13	06	268	0	56
26	32 Tauri	6.0	6	36	72	7	57	238	1	21
29	W. *vi*, 1656	8.2	4	37	109	5	30	241	0	53
29	47 Geminorum	6.0	8	05	128	9	07	234	1	02
31	B.A.C. 3138	6.3	8	20	28	8	36	2	1	16
31	B.A.C. 3206	6.3	14	58	116	16	06	305	1	08

Minima of Variable Stars of the Algol Type.

U. CEPHEI.

R. A. .... $0^h\ 52^m\ 32^s$
Decl. .... $+81°\ 17'$
Period .... $2d\,11^h\,50^m$

1893.	
Jan. 1	1 A. M.
6	1 "
11	1 "
15	midn.
20	"
25	"
30	11 P. M.

ALGOL.

R. A. .... $3^h\ 01^m\ 01^s$
Decl. .... $+40°\ 32'$
Period .... $2d\,20^h\,49^m$

Jan. 2	11 P. M.
5	8 "
8	5 "
23	1 A. M.
25	9 P. M.
28	6 "
31	3 "

R. CANIS MAJORIS.

R. A. .... $7^h\ 14^m\ 30^s$
Decl. .... $-16°\ 11'$
Period .... $1d\,03^h\,16^m$

Jan. 8	10 P. M.
10	1 A. M.
11	4 "
16	8 P. M.
17	midn.
19	3 A. M.
24	7 P. M.
25	11 "
27	2 A. M.
28	5 "

S CANCRI.

R. A. .... $8^h\ 37^m\ 39^s$
Decl. .... $+19°\ 26'$
Period .... $9d\,11^h\,37^m$

Jan. 3	6 P. M.
13	6 A. M.
22	5 P. M.
Feb. 1	5 A. M.

S ANTLIÆ.

R. A. .... $9^h\ 27^m\ 30^s$
Decl. .... $-28°\ 09'$
Period .... $7^h\ 47^m$

Jan. 1	2 A. M.
2	1 "
2	midn.
3	midn.
4	11 P. M.
5	10 "
6	10 "
7	9 "
8	5 A. M.
9	4 "
10	3 "
11	3 "
12	2 "
13	1 "
14	1 A. M.
14	midn.
15	11 P. M.
16	11 "
17	10 "
18	9 "
19	9 "
20	5 A.M.
21	4 "

S ANTLIÆ CONT.

22	3 "
23	3 "
24	2 "
25	1 "
26	1 "
26	midn.
27	11 P. M.
28	11 "
29	10 "
30	9 "
31	9 "

δ LIBRÆ.

R. A. .... $14^h\ 55^m\ 06^s$
Decl. .... $-8°\ 05'$
Period .... $2d\ 7^h\ 51^m$

Jan. 3	11 P. M.
6	7 A. M.
10	11 P. M.
13	7 A. M.
17	10 P. M.
20	6 A. M.
24	10 P. M.
27	6 A. M.
31	10 P. M.

U CORONÆ.

R. A. .... $15^h\ 13^m\ 43^s$
Decl. .... $+32°\ 03'$
Period .... $3d\ 10^h\ 51^m$

Jan. 17	6 A. M.
24	4 "
30	2 "

Two New Asteroids.—These were both discovered by means of photography. 1892 J was found on plates exposed by Wolf at Heidelberg, Sept. 25 and 30. Its position, Sept. 30, at 12^h Berlin mean time was: R. A. $0^h\ 21.^m7$; Decl, $-2°\ 50'$. Daily motion $-1^m.03$ and $-1'$.

1892 K was found on plates by Wolf, Oct. 17 and 20. Its position Oct. 20, $9^h\ 50^m$ Greenwich mean time was: R. A. $2^h\ 18^m\ 38^s$; Decl. $+18°\ 08'$.

COMET NOTES.

Three New Comets have been discovered during November. The first was discovered by Mr. Edwin Holmes, of London, Eng., whose letter to the *English Mechanic* we print below. It is a bright telescopic comet, barely visible to the naked eye but easily seen with an opera-glass. It has attracted unusual attention from the fact that it appeared in the direction from which Biela's comet might be expected to approach the Earth. Dr. Berberich, of Berlin, immediately called at tention to this fact, and several astronomers, assuming the comet to be Biela's, calculated the distance at which it ought to be and the time when it would cross the Earth's path. This time was found to be within a few hours of the the time when the Earth would pass the same point. These statements given to newspaper reporters were widely circulated and produced the impression that there was to be a collision between the comet and the Earth about Nov. 27. Later calculations do not confirm the assumption of identity with Biela's comet. On the contrary they indicate that this comet is at a great distance from the Earth and is receding. This result is a surprise to those who have been observing the comet for it has rapidly increased in size since it was discovered. Its diameter Nov. 22 was more than three times as great as on Nov. 11, although the brightness was somewhat less. It is moving very slowly southward in Andromeda and is still near the star μ.

The second comet was discovered by Mr. W. R. Brooks on the morning of Nov. 19th. His account of the discovery is given below.

The third, the announcement of which has just been received, was discovered by Mr. Freeman at Brighton, Eng., Nov. 24.389 Gr. mean time. It is described as a faint comet, in R. A. 0^h 29^m 00^s; Decl. $+ 30° 09'$, daily motion 0^m 00^s and $- 3° 12'$. This is also in Andromeda near the Biela meteor radiant.

Discovery of Comet *f* 1892 (Holmes).—On Sunday night, Nov. 6th, at 11:45, I found a new comet in Andromeda. It was bright enough to be visible in an opera-glass through the haze prevailing. Nucleus bright, with surrounding nebulosity 5′ in diameter. No tail visible. I made the position 0^h $46.8^m + 38° 32'$ exactly 1^m 10^s preceding Σ 72. My surroundings prevented me watching for any motion. I think it must have approached rapidly, for I observed that region on Oct. 25 and observed nothing special. EDWIN HOLMES.

English Mechanic Nov. 11, 1892.

Elements of Comet *f* 1892 (Holmes).—Attempts to represent the observations of this comet by a parabola have failed. From observations by Wendell Nov. 8 and my own of Nov. 15 and 22, Mr. Sivaslian has computed the following parabolic elements:

$$T = \text{Feb. } 28.143, 1892$$

$$\left.\begin{array}{rl} \omega = & 346° \; 21' \; 56'' \\ \Omega = & 325 \;\; 43 \;\; 48 \\ i = & 24 \;\; 17 \;\; 38 \end{array}\right\} 1892.0$$

$$\log q = 0.29587$$

The residuals (O—C) for the middle place $\Delta\lambda \cos\beta = -173''$; $\Delta\beta = +160''$ cannot be very much bettered by any variation of the distance. An attempt to calculate elliptic elements from these observations showed that they were insufficient to give results of any accuracy. We decided, therefore, to wait for further observations.

From *Science Observer* special circular, No. 99 we have the following elliptic elements by Dr. Kreutz and Rev. Geo. M. Searle:

	Kreutz.	Searle.
T =	June 11	Oct. 11.9802
ω =	11° 38′	62° 19′ 02″
Ω =	333 31	325 41 16
i =	24 39	19 16 43
q =	2.1509	2.28036
e =	0.4172	0.31963
Period =	7.08 years	6.14 years.

We have no ephemeris extending beyond Dec. 5, but as the comet is bright and moving very slowly observers will have no trouble in following it through December.

Comet Holmes seen Nov. 3.—My friend Mr. W. A. Post of Newport News, Va., writes me that he saw the Holmes comet on the night of November 3d. "but thought it some well known nebula." He was using a five-inch Byrne's glass at the time. He sends a sketch showing the comet rather oval as he remembers it.
New York, Nov. 16, 1892. R. M. SMYTHE

Discovery of Comet *g* 1892 (Brooks).—On the morning of November 19 at 15 hours, Eastern Standard Time, I discovered a rather bright nebulous object which I soon suspected to be a comet. The position of the object was R. A. $12^h\ 56^m\ 40^s + 12° 59'$.

It was therefore in that very nebulous region of Virgo and Coma Berenices. But I had no record of such an object in that position. The nearest was Nebula No. 4880 of the N. G. C. = W. H. III 83, which, allowing for precession, came very nearly in the same declination, but was two minutes west of my object in R. A. Moreover, that nebula was described as "considerably faint," and my object was brightish in the 10-inch refractor.

The sky clouded before I could be quite sure of motion, although my impression of the direction of motion proved to be correct. A telegram was at once transmitted to Harvard College Observatory, where the discovery was confirmed by Mr. Reed, and a position secured by Mr. O. C. Wendell, as follows: Nov. 21st, $16^h\ 44^m\ 38^s$ Camb. M. T. R. A. $12^h\ 59^m\ 15.63^s + 13° 50' 27''.3$ This gives a slow motion in a northeasterly direction.

The comet is a comparatively easy one, fairly large, and has considerable condensation, with which the coma is not quite concentric. WILLIAM R. BROOKS.
Smith Observatory, Geneva, N. Y., Nov. 25, 1892.

Comet *e* 1892 (Barnard, Oct. 12).—We have had no opportunity to look for this comet during November except on Nov. 15 when we failed to find it near the ephemeris place. Mr. Barnard observed it on Nov. 7 and says: "it has faded very much since the last observations. It is scarcely probable this object can be followed much longer." The elements of this comet are found to be elliptic. Professor Krueger from observations Oct. 16, 20 and 25 obtains a period of about 10.4 years (*Astr. Nach. 3127*). Professor Schulhof has also calculated elliptic elements and calls attention to their similarity to those of Wolf's periodic comet which has just passed out of view. He suggests that the two have the same origin, are in fact parts of the same comet which separated at some time previous to 1885. In that year they were in the vicinity of Jupiter together and suffered violent perturbations by the planet. A relatively small difference in their epochs of passing peri-jove would be sufficient to produce the considerable difference in their inclinations and excentricities. Below are the elements calculated by Mr. Schulhof together with those of Wolf's comet.

	Comet Barnard.	Wolf's Comet.
$T =$	Dec. 9.0721, 1892, Paris mean time.	—
$\pi =$	18° 33′ 44″	19° 12′
$\Omega =$	207 41 45	206 22
$i =$	30 51 13	25 15
$\log q =$	0.149245	0.2022
$e =$	0.579619	0.5571

Comet *d* 1892 (Brooks, August 28).—The following elements from the *Astronomical Journal*, No. 279, were computed by Mr. George A. Hill of the U. S. Naval Observatory, from observations at Kiel, August 31, Göttingen Sept. 18 and Hamburg Oct. 7. The residuals for the middle place are $\Delta\lambda \cos\beta = +11''.5$; $\Delta\beta = -3''.1$:

$$\begin{aligned} T &= 1892,\ \text{Dec. } 28.11944\ \text{Gr. M. T.} \\ \Omega &= 264°\ 32'\ 36''.2 \\ \omega &= 252\ \ 23\ \ 21\ .9 \\ i &= 24\ \ 45\ \ 10\ .8 \end{aligned} \left.\vphantom{\begin{aligned}a\\a\\a\end{aligned}}\right\}\ \text{Mean Eqr. 1892.0.}$$

$$\log q = 9.991529 \qquad q = 0.98068$$

Ephemeris.

	h	m	s	°	″	log. *r*	Br.
Dec. 6	11	58	43.2	− 21	31.9	9.9447	30.9
7	12	04	04.7	22	27.8		
8		09	28.2	23	22.1		
9		14	53.4	24	16.6		
10		20	20.5	25	09.3	9.9498	31.5
11		25	49.4	26	01.1		
12		31	20.0	26	51.7		
13		36	51.5	27	40.8		
14		42	24.4	28	28.5	9.9575	31.5
15		47	58.3	29	14.8		
16		53	33.2	29	59.7		
17	12	59	08.7	30	43.2		
18	13	04	45.5	31	25.3	9.9676	30.9
19		10	23.0	32	06.0		
20		16	01.0	32	45.3		
21		21	39.2	33	23.1		
22		27	17.7	33	59.4	9.9792	29.9
23		32	56.3	34	34.3		
24		38	32.8	35	07.7		
25		44	10.7	35	39.7		
26	13	49	47.4	− 36	10.2	9.9920	28.4

Ephemeris of Comet *a* 1892 (Swift.)

[Computed by Geo. A. Law, student in Goodsell Observatory, from elements by Miss Gertrude Wentworth, *Astr. Jour.* No. 273].

[Continued from Page 837.]

Gr. M. T.	App. R. A. h	m	s	App. Decl. °	′	log. *r*	log. *Δ*	Br.
1892. Dec. 16.5	23	58	10.6	+ 28	39.8			
17.5		58	49.8		31.7			
18.5	23	59	29.7		23.9			
19.5	0	00	10.2		16.2	0.5670	0.5255	.011
20.5		00	51.3		08.7			
21.5		01	32.9	28	01.4			
22.5		02	15.1	27	54.3			
23.5		02	57.9		47.5	0.5720	0.5381	.010
24.5		03	41.3		40.9			
25.5		04	25.2		34.4			
26.5		05	19.7		28.1			
27.5		05	54.6		22.0	0.5770	0.5503	.009
28.5		06	40.0		15.2			
29.5		07	25.9		10.5			
30.5		08	12.2	27	05.0			
31.5		08	59.0	26	59.6	0.5818	0.5618	.008
1893. Jan. 1.5		09	46.3		54.3			
2.5		10	34.0		49.2			
3.5		11	22.1		44.3			
4.5		12	10.6		39.5	0.5866	0.5739	.008
5.5		12	59.5		35.0			
6.5		13	48.9		30.6			
7.5		14	38.6		26.4			
8.5		15	28.7		22.4	0.5914	0.5853	.007
9.5		16	19.1		18.5			
10.5		17	09.8		14.8			
11.5		18	00.8		11.2			
12.5		18	52.2		07.7	0.5960	0.5964	.007
13.5		19	43.9		04.4			
14.5		20	36.0	26	01.2			
15.5		21	38.3	25	58.2			
16.5	0	22	20.9	+ 25	55.3	0.6006	0.6072	.006

Hw to Compute the Relative Brightness of a Comet.—A subscriber asks us the meaning of relative brightness of a comet and how it is determined. Usually the unit of brightness of a comet is taken as the brightness which the same comet had at the time of its discovery, and the relative brightness is its brightness on any other date expressed in terms of that unit. The brightness is computed on the assumption that the comet shines by reflected light from the Sun only and hence varies in inverse ratio to the squares of the distances from the Sun and Earth. This is expressed by the proportion

$$B : B_0 : : \frac{1}{r^2\Delta^2} : \frac{1}{r_0{}^2\Delta_0{}^2}$$

in which B, r and Δ are respectively the brightness, distance from Sun, and distance from Earth on any date and B_0, r_0 and Δ_0 are the corresponding quantities on any other date. If B_0 is the brightness on the date of discovery and is taken as unity, then we have for the relative brightness on any other date

$$B = \frac{r_0{}^2\Delta_0{}^2}{r^2\Delta^2}.$$

If the comet gives out light of its own this law does not hold true.

The Shower of Bielid Meteors.—Although the Holmes' comet did not turn out to be Biela's, the prediction that there would be a shower of meteors, when the Earth passed the track of the latter comet, had a partial fulfilment on the evening of Wednesday, Nov. 23. On that evening a shower of meteors radiating from the constellation of Andromeda was observed quite generally throughout the United States. At Northfield, the display had already begun at dark and continued so long as it was watched, *i. e.*, until nearly midnight. The meteors were quite numerous, falling in all quarters of the sky. As many as 15 to 20 on the average could be counted by one person each minute. They were of all magnitudes from the faintest visible to as bright as Jupiter.

We have reports of similar observations from many points, but have space only for the following, which comes from Princeton, N. J. It is unsigned, but is evidently from Professor C. A. Young. Thursday, Friday and Saturday nights were cloudy at Northfield. Sunday night was clear during the first half but no meteors were seen.

The Meteor Shower of Nov. 23, 1892.—On the night of the 23d we had here a fine meteoric display. At 7 o'clock the meteors were already numerous, and from 7:30 until 12:30, when it clouded up, they were falling at the rate of 100 in from four to five minutes. At ten o'clock two observers, standing in an open space and facing in opposite directions, counted 104 in five minutes, and again at eleven they counted 100 in four minutes and a half. The number seen by observers sufficiently numerous to cover the whole sky exhaustively, would have been from four to five times as many, and reckoning on that basis, the total number that fell within our range of vision at Princeton must have been at least 30,000 during the five hours.

The meteors were evidently "Bielids," the radiant at 8:30 being a roughly circular area about 4° in diameter with its centre at R. A. $1^h\ 20^m$, Dec. + 41° 30'. At 10 it seemed to be a little more definitely limited, and several nearly stationary meteors fixed its position as R. A. $1^h\ 30^m$. Dec. + 40° 30', very near Upsilon Andromedæ. At 11, it was again determined, and then it came out R. A. $1^h\ 40^m$, Dec. + 40°. Whether this apparent change in the position of the radiant was real or not, I am not quite certain, but a motion of the radiant, very similar in amount and direction, is given by Denza in his observations of the shower of 1885: (see *Nature*, vol. 33, page 151). At that time the mean position of the radiant was about 3° N. W. of its place this year.

Holmes's comet, barely visible to the naked eye, was about 10° west and 4° south of the radiant.

It is worth noting that the Earth's heliocentric longitude at the time of the shower the other night was only 62°, and not 65°, which (65°) was the longitude of the descending node of Biela's orbit at the last appearance of the comet in 1852, and was the longitude of the Earth at the time of the showers of 1872 and 1885. The fact suggests the inquiry whether such a recession of the node can be accounted for by perturbations (probably by Jupiter) since 1885.

It is obvious also that if the meteoric swarm encountered by the Earth in 1872 and 1885 was really moving in the orbit of Biela's comet, which when last observed had a period of 6.6 years, then the swarm encountered on Wednesday night, just 7 years later, must be an entirely different one: unless indeed a retardation of nearly five months can be accounted for by perturbations within the last six years, which is hardly likely.

Most of the meteors were very small, not exceeding the 5th magnitude; but a few, perhaps ten per cent of the whole, were above the 2d. In the course of the night four were observed which rivalled or surpassed Jupiter.

The brighter ones generally left bluish trains which remained visible for four or five seconds. The smaller ones often came in "flights," three or four together, and fully half of the paths were more or less curved and wavy from the resistance of the air.

Last night (Nov. 24th) was mostly overcast, but there were occasional breaks in the clouds, and a careful watch showed three or four meteors which might possibly be Bielids: but it was clear that there was nothing like a "shower" in progress.

Princeton, N. J., Nov. 25th, 1892.

Meteors of November 23, 1892.—The meteors of Wednesday night, Nov. 23, 1892, have attracted general attention. They were seen here in all parts of the sky at almost every moment. They did not come at a strictly constant rate, though nearly so. On the average a single observer could see from 50 to 60 fairly bright ones every five minutes, which corresponds to a daily rate of from 400,000,000 to 500,000,000 on the hemisphere of the Earth towards the radiant. The radiant, as observed here, was very approximately at

$$\alpha = 1^h\ 39^m \qquad \delta = +42°.$$

Palo Alto, Cal., Nov. 28, 1892. W. J. HUSSEY.

NEWS AND NOTES.

Serious delays have made us unusually late this month. With better office facilities and other more favorable arrangements, our publication will appear promptly and regularly hereafter.

A large number of subscriptions expire with this number. It is especially requested that renewals be *promptly* made that our mailing list may be corrected for the January issue.

Mounting of the 40-inch Telescope for Chicago University.—Messrs. Warner & Swasey, of Cleveland, Ohio, have been awarded the contract for mounting the 40-inch telescope for the Yerkes' Observatory of the University of Chicago.

If subscribers interested in still further improvements of ASTRONOMY AND ASTRO-PHYSICS for the coming year, will do us the favor of bringing this publication to the notice of the friends of science generally, we are sure that its merit will commend it favorably, and that our subscription list will be greatly inereased. With such increase greater outlay will be made for the illustrated matter, in amount or quality, or both, as the demands of current astronomy shall decide.

Aids for Temporary Star Search.—The following extract from a note by Mr. D. E. Packer in *English Mechanic*, Nov. 11, 1892, may be of use to some of our readers:

"During the recent summer months, in our leisure evenings, Mr. Morris, of Cambridge, and myself were engaged in searching the heavens (especially the Milky Way region) for the detection of new stars. In order to expedite our search, we adopted a scheme which, I think, will find favor with those who are similarly occupied on starry nights, and for which we strongly advocate a trial. We used the excellent maps in Schürig's "Tabulæ Cœlestis," which give all, or

nearly all, stars down to the sixth magnitude. The charts were photographed on quarter plates, and the negatives, backed by tissue paper or an ordinary screen glass, were projected in front of a small bull's-eye lantern. A convenient method was thus obtained of comparing any portion of the chart with its corresponding portion in the heavens. It only required the use of an ordinary magnifier to enlarge any portion of the photographed chart to render comparison easier, and the apparatus was complete. The ease and comfort with which considerable areas of sky were swept over, and the enormous saving of time which this method affords over the ordinary method, a trial will suffice to show. Regions near the zenith were viewed by projection in an ordinary mirror, the photographed chart being correspondingly inverted."

Cause of Brightness of the Limb of Mars.—Is it not probable that the apparent increase in brightness of the disc of Mars toward the limb is an optical illusion due to the contrast with the surrounding sky, and to the fact that the spherical form of Mars causes the markings to disappear near the limb? If so, might it not be proved by differential photometric observations of different portions of the disc made when Mars is near opposition? ORMOND STONE.

Oct. 29, 1892.

Peculiar Stellar Spectra.—An examination by Mr. A. E. Douglas of the photographs taken at the Arequipa station of this Observatory has revealed the following peculiar stellar spectra.

1. A. G. C. 16710. Type IV. Identification uncertain.
2. A. G. C. 19254. Type IV.
3. —15° 4923. Type IV. Identification uncertain.
4. S Carinæ. Hydrogen lines bright.
5. X Ophiuchi. Hydrogen lines bright.
6. N. G. C. 3918. Gaseous character confirmed by photograph.
7. N. G. C. 6618. " " " " "

Nos. 3, 4 and 7 had previously been discovered independently by Mrs. Fleming from other plates already received in Cambridge.

Harvard College Observatory, Cambridge, Mass. EDWARD C. PICKERING.

Nov. 10, 1892.

Occultation of Mars, July 11, 1892.—The occultation was observed at the Dearborn Observatory with the 18½-inch refractor, power 200, and the times were recorded with the printing chronograph. At immersion, owing to the low altitude of the moon, the definition was poor; at emersion the seeing was very steady.

1st Contact	10^h	14^m	$28^s.2$	Local	M. T.
2 "	10	15	25 .9	"	"
3 "	11	09	51 .8	"	"
4 "	11	10	59 .0	"	"

Northwestern University. G. W. HOUGH.

The Fifth Satellite of Jupiter.—Professor Barnard's new satellite of Jupiter was seen with the 18½-inch refractor of the Dearborn Observatory, on Oct. 15th, from 11^h 37^m to 12^h 30^m standard time. A number of diagrams were made, showing its position with reference to the 1st satellite which was quite near when first seen. A rough setting of the micrometer lines gave 35″ as its distance from the following limb of Jupiter.

I had looked for the satellite on a number of nights previously, using an ephemeris based on the period 11^h 49^m and of course without success.

On Oct. 14, Mr. S. W. Burnham kindly communicated to me an observation made by Professor Barnard on Oct. 7. On comparing this observation with that made at the date of discovery, I inferred that the elongation occurred about 5 minutes earlier each day.

I saw the satellite again on Nov. 11, 9^h 21^m a rough measure referred to the IVth satellite gave 36″ as its distance from the limb of Jupiter.

The satellite could only be seen with power 925, using an occulting bar of tinfoil to hide the planet. It is too difficult an object to make measures of precision with the 18½-inch object-glass.

It is much more difficult than either Ariel or Umbriel, the two inner satellites of Uranus, both of which I have observed under ordinary atmospheric conditions. The Vth Satellite of Jupiter, on the contrary, requires the best possible atmospheric conditions to see it at all with the 18½-inch object-glass.

Northwestern University. G. W. HOUGH.

GENERAL INDEX TO VOLUME XI.

NOTE.—The January number contains pages from 1-96, Februay, 97-176; March, 177-256; April, 257-352; May, 353-448; June, 449-544; August, 545-640; October, 641-752, November, 753-848, December, 849-944. No further reference will be made to the monthly issues of this Journal. The numbers following the tiles are the pages of the volume. This volume is numbered XI in continuation of the series of the ten volumes previously published under the name of THE SIDEREAL MESSENGER.